PETROLEUM DEVELOPMENT AND TECHNOLOGY

1941

PETROLEUM DIVISION

A. I. M. E.

A.b.L.

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AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS

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PETROLEUM DEVELOPMENT AND TECHNOLOGY

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PETROLEUM DIVISION

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Multiple-phase Hydrocarbon Systems. By D. J. VINK, A. M. AMES, R. A. DAVID and D. L. KATZ. *Oil and Gas Jnl.* (Nov. 21, 1940) **39** (28).

A Study in Well Spacing, Sinclair-Moren Pool, Young County, Texas. By M. G. CHENEY. A.I.M.E. *Tech. Pub.* 1253, *Petroleum Technology*, Nov. 1940.

Some Factors Influencing Recovery of Condensate in Recycling Operations. By L. S. REID, with discussion by Kenneth Eilerts. A.I.M.E. *Tech. Pub.* 1259, *Petroleum Technology*, Nov. 1940.

Tank Steamer Transportation of Petroleum. By V. R. GARFIAS and J. W. RISTORI. *Oil Weekly*, April 1, 1940.

FOREWORD

It is anticipated that the most important event featured by the Petroleum Division during the year 1941 will be an increase in the number of issues of Petroleum Technology from four to six. This change has been authorized by the Executive Committee, and is undertaken both for the purpose of improving the service of the Division to its members through more prompt distribution of the technical papers and for the purpose of handling the increased number of articles submitted for publication.

As forecast by the able chairman of the Division during 1940, Mr. T. V. Moore, the newly organized East Texas Section has proved to be an outstanding one, and its periodical meetings have already provided an open forum for the engineers working in or near Shreveport, Tyler, Kilgore, Van, Dallas and Fort Worth.

Engineers who are associated with companies that may have the good fortune to discover new fields during the present or succeeding years are urged at this time to place before their executives the vital importance of the acquisition of basic reservoir data during the drilling and immediately after the completion of initial wells. Much of such information can be acquired only during the early life of a pool, and it has already been demonstrated that operating practices can be vastly improved where such data have been made available.

Preparations are well under way for the technical meetings to be held at Dallas, October 16, 17 and 18, and at Los Angeles, October 30 and 31, so that exceptional programs may be anticipated for both occasions.

The Division takes opportunity to express its appreciation of the cooperation afforded by the personnel at the New York headquarters of the Institute, and to thank especially the various committee chairmen, vice-chairmen, and members of the Division, and all others that participate actively in the affairs of the Institute.

Eugene A. Stephenson, *Chairman*,
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In 1936 the Institute established the Anthony F. Lucas Gold Medal, to be awarded from time to time "for distinguished achievement in improving the technique and practice of finding and producing petroleum." These awards are sponsored by the Petroleum Division.

Captain Lucas was a pioneer in the oil industry, one of the early wildcatters and a leading mining and petroleum engineer. He was famous as the discoverer of Spindletop. He became a member of the Institute in 1895 and in 1913 was the first Chairman of the Petroleum and Gas Committee of the Institute, the forerunner of the present Petroleum Division. He also headed the Committee in 1914, 1917 and 1918.

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To J. Edgar Pew, February 1937
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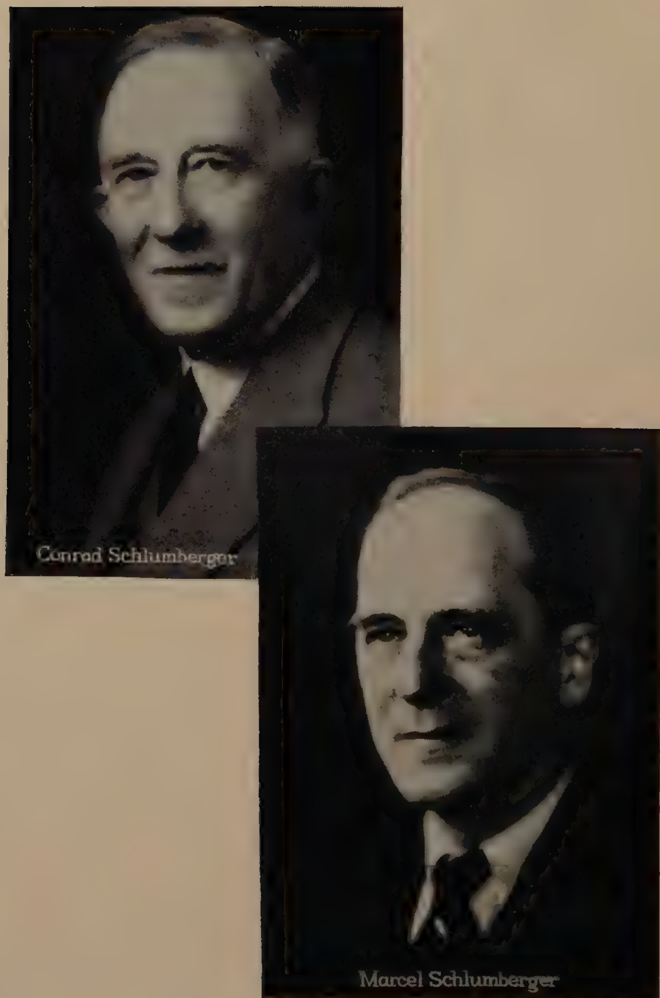

Anthony F. Lucas Medalists, 1941 Award

Chapter I. Production Engineering

Temperature Surveys in Oil Wells

By C. V. Millikan*, Member A.I.M.E.

(Tulsa Meeting, October 1940)

Temperature measurement in wells is an old practice and geothermal gradients have been of interest to geologists for many years.[1,2] Their application to the operation of oil wells is a more recent practice. It has long been recognized that temperature anomalies occur in drilling and producing wells but thermometers that could obtain a satisfactory record of the anomalies were not available.[3]

The normal geothermal gradient is considered as being about one degree Fahrenheit for each 60 ft. of depth.[4] This "normal" gradient varies in different areas, but whatever it may be in an area there is little variation from the surface to as deep as the drill penetrates. The normal gradient is appreciably changed by gas expanding from the reservoir into the borehole or by the movement of fluid through a borehole while drilling, producing, or circulating. It is the resulting anomalies and abnormal gradients from which conditions in wells can be interpreted. Some of the applications of such interpretations are locating the position of oil or gas sands, permeable strata in a reservoir zone, gas-oil contact, source of water, casing leaks, and the top of cement behind casing.

Thermometers

A thermometer for use in wells must be sensitive and have a low thermal lag. The sensitivity should permit recording 0.2°F. or less for differential temperatures although the actual temperature need not be more accurate than 1°F. The thermal lag should be as low as rugged construction will permit in order to allow surveys to be made in a minimum of time. Of the several kinds of thermometers, these requirements are most easily obtained with the vapor-pressure, expansion, and electric-resistance types. Thermometers for use in wells may be self-contained—that is, the complete instrument is lowered into the well and a record made of the temperature—or the thermal element only may be lowered into the well and the temperature recorded at the surface. The vapor-pressure and expansion types are more adaptable for a self-contained instrument while the electric-resistance thermometer is more suitable for surface recording of temperatures.

The self-contained instrument can be run against high pressure on a single wire line with only one operator required. The instrument and its hoisting equipment is easily portable and can be mounted on a small car. The disadvantages are a somewhat greater thermal lag and the necessity of completing a run before any temperature or temperature anomaly is known.

A surface-recording thermometer has the advantage of being somewhat more sensitive and of having a lower thermal lag. The operator can see what anomalies are encountered and can immediately change the running conditions of the instrument or the well conditions in order to obtain the most

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* Chief Engineer, Amerada Petroleum Corporation, Tulsa, Oklahoma.

[1] References are at the end of the paper.

precise determination of the anomaly. The disadvantage is the large cable that must be used to carry the insulated electric conductor. A truck is required to handle the equipment and two or three men to operate it. The large size of the line makes it much more difficult to run against high pressure. Gas and oil, especially under high pressure, make the life of the insulated cable short.

The part of the hole in which the temperature anomaly is expected should be filled with liquid if possible, because of the greater rate of heat transfer and consequent quicker response of the thermometer to a change in temperature.

Interpretation

The value of a record of the temperature in a well must come from interpretation of the temperature anomalies or of a change in thermal gradient. The well should be operated before or at the time the temperature survey is being run, in the manner that will establish the greatest temperature anomalies possible. Except when the anomaly depends on the flow of fluid, such as casing leak, thief sands, and pumping fluid into a porous zone, pressure equilibrium should exist in the well while the temperature survey is being made. It should be remembered that shutting in a well does not stop fluid movement in the well bore. Production from the well is stopped but fluid will continue to come into the hole until pressure equilibrium has been established. Running a temperature survey too soon after a well is shut in may obtain an erratic anomaly. On the other hand, waiting too long may result in no anomaly because of approaching temperature equilibrium.

A temperature survey may be helpful in determining stratigraphy.[5–7] Since different formations have different heat capacities, appreciable anomalies exist in a hole after rotary drilling is completed. A temperature survey may locate the depth of certain formations more precisely than they can be placed from casual samples and driller's logs, or may give a check on their depths as determined by other means. Unless considerable work has been done with them it is doubtful whether temperature surveys would be an acceptable substitute for good samples or electric logs.

Temperature surveys have been used with some success for determining the point to plug back to upper prospective producing horizons. In some places satisfactory anomalies can be obtained by filling the hole with fluid and making temperature surveys. A better anomaly is usually obtained by circulating fluid for several hours, then running temperature surveys during the first few hours after circulation is stopped. The circulating fluid should be as cold as possible to establish a greater temperature differential and thereby a more pronounced temperature anomaly. Anomalies obtained must be interpreted with reference to all other information on the well. In general, one may expect an oil or gas sand to return to normal temperature more slowly than other formations and therefore appear as a low-temperature anomaly. A salt-water sand would probably transfer heat more rapidly and therefore appear as a high-temperature anomaly. If the hole is filled with liquid without circulating, the more probable effect of oil, gas, and salt-water sands on the temperature gradient would be the reverse of that obtained after circulation of cold liquid. This may be good theory, but in practice it is better to interpret the temperature survey in the light of all information available on the well, whether the anomaly be above or below the average temperature gradient.

Examples

Fig. 1 shows the plotted temperatures taken in an open hole, which shows correlation of temperature anomalies and sands. All of the sands contained salt water. While this survey was run in open hole, similar

anomalies have been obtained in cased holes by preparing them for the temperature survey by circulating cold water for several hours.

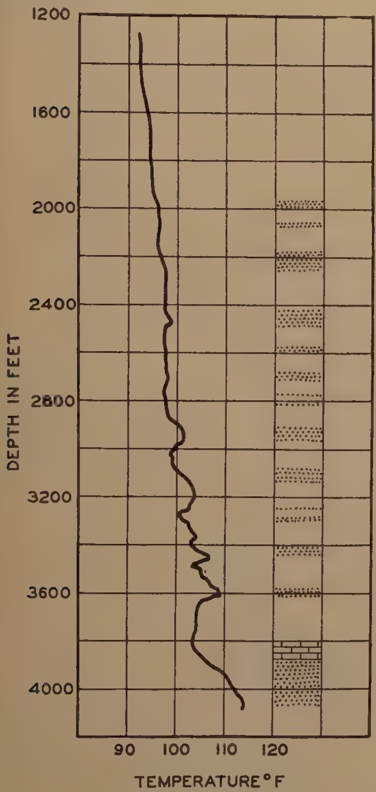

FIG. 1.—CORRELATION OF TEMPERATURE GRADIENT AND WATER SANDS.

A formation may have strata of low permeability, which are difficult to determine from examination of samples. If the formation contains gas under high pressure, the presence and depth of the permeable streaks may be determined from shows in the dri ling mud, but the determination may have considerable error. A temperature survey would show the depth of the producing strata and indicate the relative productivity of each.

Fig. 2 shows a determination of the location of gas-producing strata in a sand zone that had been drilled with rotary. The well was producing about four million cubic feet per day between strings of pipe and the recording thermometer was run continuously through the drilling mud in the inner string. The temperatures showed

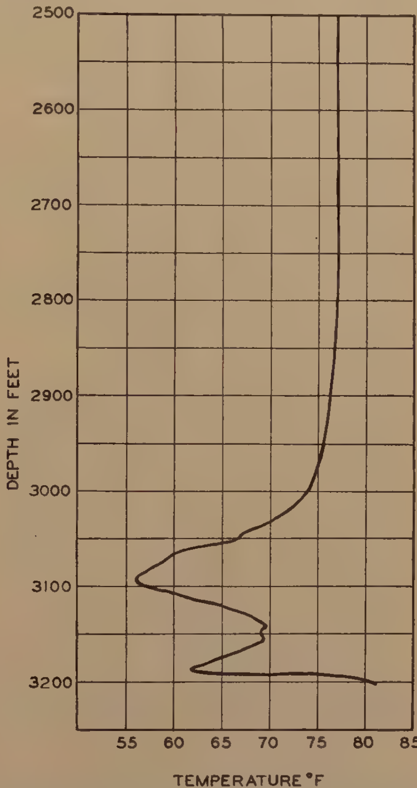

FIG. 2.—WELL PRODUCING GAS THROUGH BRADENHEAD AND THERMOMETER RUN INSIDE CASING TO DETERMINE DEPTH OF GAS-PRODUCING STRATA.

that the most productive gas sand was from 3080 to 3095 ft. and from 3175 to 3185 ft., with a less productive streak from 3145 to 3150 feet.

A determination of the gas-oil contact is important when it is desired to rework a well to shut off gas. The temperature survey is preferably taken while the well is producing. Production should be from the casing unless it is certain that the bottom of the tubing is several feet above the base of the gas sand. Production should be at the highest safe rate. Gas expanding as it

comes from the formation into the hole causes a greater decline in temperature than occurs where it is not being produced. The base of gas production would be

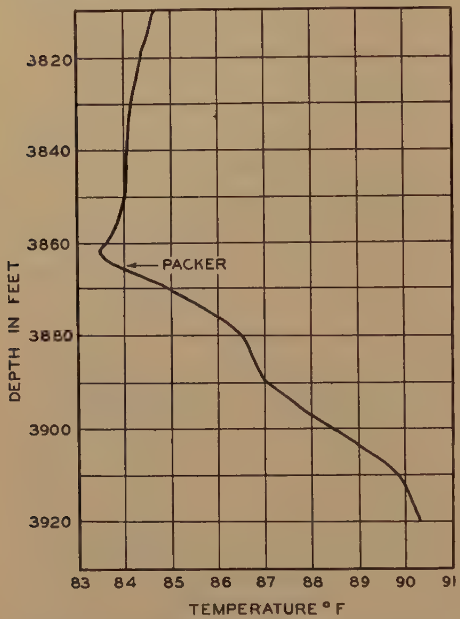

FIG. 3.—DETERMINATION OF DEPTH AT WHICH TO SET PACKER TO REDUCE GAS-OIL RATIO.

indicated by an increase in temperature, a point that may or may not be the top of oil production.

Fig. 3 is the temperature recorded in a well that was producing at the rate of 275 bbl. of oil and 6000 M cu. ft. of gas per day through the casing during the survey. The bottom of the tubing was at 3925 ft. The base of the gas zone was interpreted as being 3864 ft., and the principal oil zone from 3880 to 3890 ft. A tubing packer set at 3865 ft. reduced the gas-oil ratio from 22,000 to 3,600 cu. ft. per barrel.

Sometimes there is not enough expansion of gas as it comes from the reservoir into the hole to establish a reliable anomaly. Under such conditions the porous strata may be located by running cold water into the hole, which cools the formations into which it flows more than it does the formation it moves past. A temperature survey while the water is moving will probably be more positive in determining the lowest permeable stratum, but a better interpre-

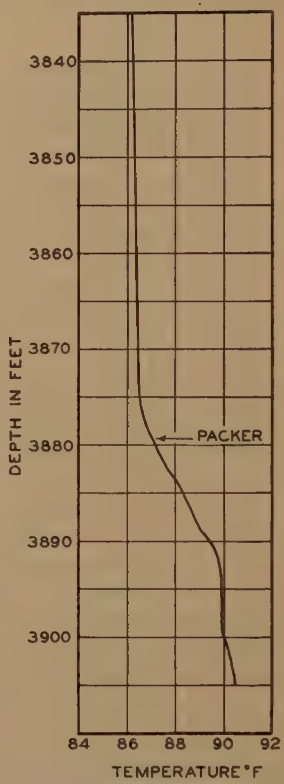

FIG. 4.—AFTER COLD WATER WAS PUMPED INTO WELL, TEMPERATURE SURVEY INDICATED BASE OF MAIN POROSITY.

tation of the entire zone probably can be obtained by making the temperature survey 2 to 4 hr. after water injection is stopped. Surveying several times during and following water injection will give a better chance of obtaining the maximum anomalies in the hole, and also will check readings to reduce the probable error of interpretation.

Fig. 4 is a temperature record taken to determine a point for setting a packer to reduce gas-oil ratio. Temperatures taken while the well was producing and after shutting in a short time did not give anomalies that could reasonably be interpreted as to the base of gas production.

Cold water was run into the well at the rate of 10 bbl. per hour for several hours prior to and continued while running the thermometer. The base of the main porosity was interpreted to be at 3875 ft., which was assumed to be the base of the gas-producing zone. At the time the test was run, the well had a potential of 50 bbl. of oil per day with a gas-oil ratio of 20,000. A packer was set at 3879 ft. and the well acidized, after which its potential was 75 bbl. of oil daily through tubing with a gas-oil ratio of 1100.

Drilling fluid is sometimes lost and occasionally there is some uncertainty as to the depth of the thieving formation. It could be found by running a recording thermometer 2 to 4 hr. after pumping of fluid into the formation is discontinued. A definitely cooler interval would be interpreted as the offending formation if the temperature of the drilling fluid is colder than the formation; or if warmer than the formation, the anomaly would be an increase in temperature. If only the maximum depth of a thieving formation is desired, it could be determined by raising the drill pipe above the formation and running the thermometer while mud is being pumped into the hole or immediately after pumping is stopped.

Source of water is usually difficult to determine. The temperature of all fluids in the reservoir is equal. Water expansion is too low to give a measurable change in temperature. The anomaly if present is caused by the cooling action of expanding gas as it emerges from the reservoir into the hole, resulting in an increase in temperature at the base of the oil and gas zone. To establish the anomaly, therefore, it is necessary to lower the pressure below the bubble point in order to obtain the cooling effect of the expanding gas. Many times it is not safe to produce the well at a rate high enough to reduce the pressure below the bubble point, and even where conditions in the well can be set up to establish an anomaly, the latter may be too small to be interpreted definitely.

The temperatures given in Fig. 5 were obtained on surveys made to give information on the depth to plug back for shutting off water. Curve *A* is the thermal gradient

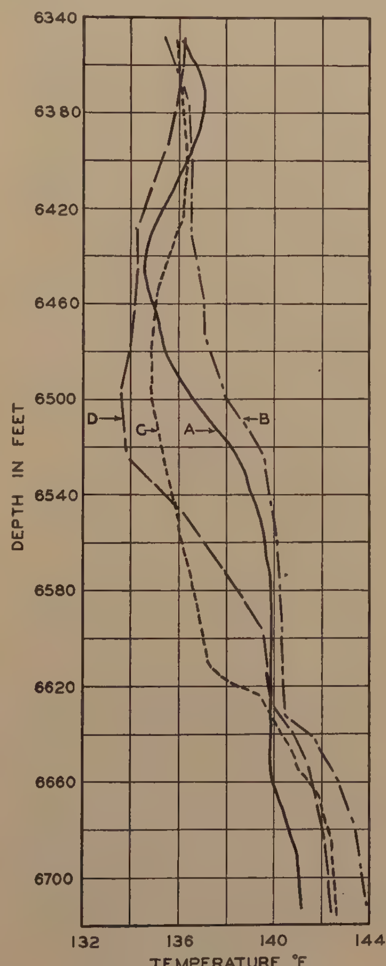

FIG. 5.—TEMPERATURE CURVES: (*A*) WELL SHUT IN 20 DAYS, (*B*) FLOWING, (*C*) 30 MINUTES AFTER SHUTTING IN, (*D*) 4 HOURS AFTER SHUTTING IN.

Interpretation: gas at 6440 feet; no oil below 6635; water below 6650.

after the well was shut in 20 days. Curve *B* was taken while the well was producing 25 bbl. of oil and 7 bbl. of water an hour through casing, with a gas-oil ratio of 4000 cu. ft. per barrel. The well was then shut in and curve *C* was run ½ hr. later, and

curve D 4 hr. later. This group of curves is an example of the different anomalies that can be obtained in the same well under different conditions, and demonstrates the

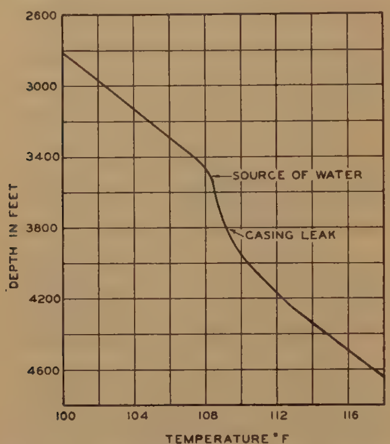

FIG. 6.—TEMPERATURES IN WELL IN WHICH WATER COMING FROM 3515 FEET WAS LEAKING THROUGH HOLE IN CASING AT 3810 FEET.

necessity for properly preparing a well for a temperature survey. The interpretation of the temperature curves was that most of the gas was coming from 6440 ft., that there was no oil production below 6635 ft., and that most of the water was coming in from below 6660 ft., although some water might be coming in as high as 6650 ft. Plugging back to 6662 ft. reduced the water production about three-fourths, and the well produced clean oil after it was plugged back to 6647 ft. There was no change in the rate of oil production.

Casing Leaks

A casing leak is one of the most insidious troubles that can develop in a producing well. Where there is communication between the point of leakage and a porous formation, leakage will be into the well if the well pressure is lower than the outside pressure or out of the well if the pressure inside the casing is higher than the outside pressure at the point of leakage. Often there is no indication in the producing well that any leakage is occurring. Leakage of water into the well may be small and assumed to be produced from the oil horizon. It would probably be recognized by a lower than normal temperature gradient below the leak. If the leak is out of the casing and small, there will probably be gas expansion at the point of leakage and a drop of temperature. A large leak will cause a sharp increase of temperature at the leak and a lower temperature gradient but a higher temperature than normal from the point of leakage to the producing formation.

Fig. 6 is a curve giving the temperature in a pumping well that had a water leak in the oil string of casing. The curve is normal to 3515 ft., which was the source of the water. The hole in the casing is indicated between 3750 and 3900 ft. and was found at 3810 ft. by pumping a plug down. The velocity of the water flowing behind the casing from the water sand to the hole in the casing was so rapid that there was little change in temperature in this interval. When the water came inside the casing the velocity was reduced enough for the gradient to come back almost to normal but the actual temperature was appreciably below normal.

Fig. 7 shows two temperature curves taken on successive days in a well having a small casing leak. Calculations showed that the fluid level was below the point of leakage when the temperatures given in curve A were measured. The following day, when the temperatures given in curve B were measured, the fluid level had risen above the point of leakage and therefore a smaller temperature anomaly was present. A packer was run and the annular space between the casing and tubing was filled with mud. A temperature survey then showed no anomaly.

Repairing a subsurface leak from one formation to another is often an uncertain operation. Pumping mud or cement into the point of leakage may not stop it even though at the surface there may be no apparent movement of fluid. A temperature

survey will show an approximately normal gradient if the job is successful or an irregular temperature will still be present if the migration has not been stopped.

Fig. 8 shows the temperatures obtained by surveys in a well having a large oil leakage through split casing at 1060 ft. The first indication of the leak was an abnormally low bottom-hole pressure, and it was located with the thermometer, which gave the temperature record shown by curve *A*. There was no pressure on the bradenhead between the surface casing and the oil string. Heavy mud was pumped into the tubing until the pressure on the tubing and casing was reduced to atmosphere. Before work was started on the well, another temperature survey was run, which gave the temperatures shown in curve *B* and proved that the flow of oil and gas still continued, although there was no indication of the flow at the surface. A second attempt to kill the well also failed and after the third attempt the temperature survey proved that the flow had been stopped. Curve *C* is the normal thermal gradient in wells in the area.

Setting of Portland Cement

Setting of Portland cement is an exothermic reaction. The amount of heat generated is governed by the composition of the cement and the rate of generation depends on fineness of the grind, or, more precisely, the total area of the cement particles. Tricalcium aluminate is the most important heat-forming chemical and tricalcium silicate second. Most Portland cements generate from 60 to 115 cal. per gram during hydration, depending on composition. Cement behind cemented casing will generate enough heat to be measured inside the casing and a temperature survey in the well will give an increase in temperature at the top of the cement behind the casing.[5,6] The greatest anomaly exists probably between 4 and 8 hr. after the cement is placed. Generally an appreciable temperature anomaly can be measured after several days. The amount of temperature increase varies from a small anomaly not larger than may be caused by a change in formation to an increase of

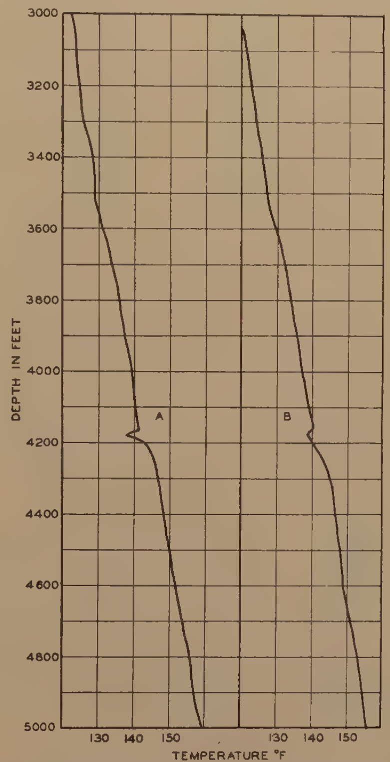

FIG. 7.—TEMPERATURE ANOMALY CAUSED BY: (*A*) GAS, (*B*) OIL AND GAS LEAKING THROUGH SMALL HOLE IN CASING.

several degrees. Some increases have exceeded 50°F. A small increase interpreted as the top of the cement may be further indicated by a change in the gradient and a more irregular gradient than might reasonably be expected from variation of the heat capacities of the formations penetrated.

Fig. 9 contains three curves showing the temperature record obtained to determine the position of the top of the cement behind the casing. The thermometer was run from 24 to 36 hr. after cementing. The interpretation of curves *B* and *C* is definite and the interpretation of curve *A* is based on the characteristic irregularity of the tem-

perature immediately below the top of the cement.

Value of Survey

The examples of temperature curves that have been presented were selected because

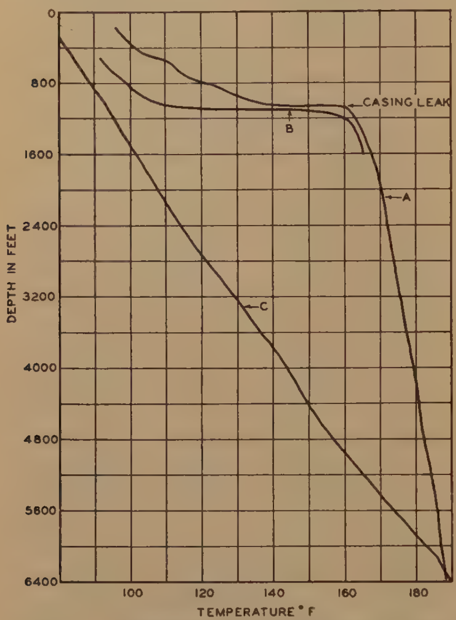

Fig. 8.—Temperature resulting from leakage through split casing: (*A*) during leakage, (*B*) after pumping mud into well until surface pressures were zero, (*C*) normal temperature gradient for area.

they show clearly the value of the temperature survey in solving specific problems. A temperature survey to show the presence and depth of a leak in the casing is not likely to result in any problem of preparing the well for the survey or of interpreting the temperatures. The same is true of determinations of the top of cement behind the pipe. A temperature survey from which it is expected to correlate formations, interpret the location of probable oil or gas sands behind casing, or determine gas-oil contact or source of water frequently tax the ingenuity of the operator to condition the well so as to obtain a temperature gradient or anomalies that represent conditions within the well. The temperatures obtained on a survey or series of surveys frequently require considerable study and comparison with electric logs, sample logs, production history, and other information

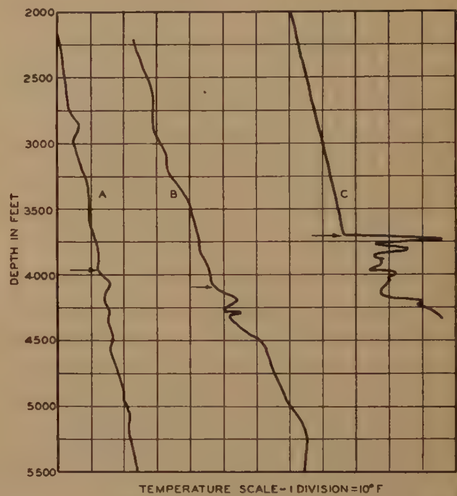

Fig. 9.—Effect of cement behind casing on temperature gradient.
Arrows indicate top of cement.

on the well before an intelligent and reliable interpretation can be made.

A recording thermometer is a recent addition to the instruments used by the petroleum engineer. It has proved its value and promises to become increasingly important as more is learned about preparing a well to obtain better anomalies, and more experience is gained in correlating anomalies with conditions in wells.

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DISCUSSION

R. E. Heithecker,* Bartlesville, Okla.—Mr. Millikan has presented some unusual applications of the recording temperature gauge, a precise instrument developed and used generally to determine accurate temperatures of producing formations or the temperatures of mixtures rising in the flow string.

The Bureau of Mines tested a gas well, which, with only a negligible gas withdrawal, had shown a decline in shut-in wellhead pressure of 850 (from 2295 to 1445) lb. per sq. in. gauge during an interval of about one year. Flow tests on the well by the operator showed that the decline was not due to accumulation of liquid. Tests of a well almost a mile away, considered to be producing from the same horizon, did not show any unaccounted-for decline in pressure, so it seemed that the abnormal pressure decline must be the result of some subterranean leak.

A temperature survey was made with Bureau of Mines equipment in the well showing the abnormal decline while it was shut in at the surface. Between the depths of 2000 and 2200 ft., a temperature rise from 107.5° to 140°F. was noted (a gradient of 16.25° per 100 ft.), whereas the normal gradient between those depths, as reflected by a temperature traverse in the neighboring well, was approximately 2°F. per 100 ft. The data indicated that gas from the reservoir at 5952 ft. was flowing into a thief sand at a depth of approximately 2200 ft., but it was not determined definitely whether the gas entered the thief sand through a leak in the pipe between the 2200-ft. level and the bottom of the casing or traveled upward outside the casing.

The operator repaired the well by setting and cementing a new string of casing inside the old pipe. The results of the reconditioning are shown through a rise of wellhead pressure from 1445 lb. per sq. in. gauge on Feb. 12, 1938, just before the reconditioning to 1715 lb. per sq. in. gauge on July 19, 1940—an increase of 270 lb. despite withdrawal of gas from the well. The temperature at the 2200-ft. level decreased from 140° to 128°F. during the same period.

The detailed analyses of the temperature surveys and back-pressure tests of this well in March and June 1938 and March 1939, as given in Bureau of Mines *Report of Investigations* 3493, by Schellhardt, Dewees, and Barlow, published in March 1940 and the additional data from the test of July 1940, may be of interest in connection with this contribution by Mr. Millikan.

* Senior Petroleum Engineer, U. S. Bureau of Mines.

A New Method of Constructing Subsurface Models

By Kenneth M. Bravinder,* Dean H. Sheldon,* Junior Member, A.I.M.E., and Jonathan E. Koogle*

(Los Angeles Meeting, October 1940)

The solution of subsurface geological problems requires an analysis of vertical and horizontal dimensional relationships. For many, the ability to visualize structures in three dimensions is not easily acquired, and for areas where the structural conditions are complicated by faulting the need arises for illustrative models. This has led to the many forms of peg models, in which the usual course of construction includes a peg for the well bore, and the suspension of strings from peg to peg to illustrate the formation correlation between wells, thus developing the usual folds and flexures. Such models proved unsatisfactory for the analysis of fault problems. Consideration was then given to the use of transparent materials.

A model of the Dominguez oil field was constructed in 1935, which consisted of a series of glass panels from well to well on which the formations were shown in color. This model, though serving its purpose at the time, proved to be impractical from the standpoints of cost, breakage hazard, and extreme difficulty in maintenance. The cost of materials was estimated to be approximately $300, and the construction required the services of one man for a period of from 10 to 12 months. Maintenance after actual construction was an additional expense.

Consideration was then given to the use of celluloid, and after some experimental work it was found that the advantages in its use were: (1) a short construction time, (2) ease of handling the material, (3) sections are easily reworked, (4) low cost.

Construction

It would be of little value to recount here the difficulties encountered in the building of the first celluloid model. The conclusions drawn, however, suggest the following procedure for those who contemplate the construction of such a model:

1. *Determination of the Scale.*—Accurate geological interpretation requires the use of the same scale horizontally and vertically. It should be emphasized that the limited size of the celluloid sheets (20 by 48 in. maximum dimensions), the area to be studied, the maximum depths to be plotted, and area of possible future development are the controlling factors in adopting a scale to be used.

2. *Construction of the Base.*—A satisfactory base may be constructed by using two pieces of three-ply wood separated by strips of 1 by 2-in. material. This type of construction prevents warping of the base. The size of the base is determined by the dimensions of the area to be studied plus 5 in. on all sides. A map of the same scale as that adopted for the model, indicating the lines of section to be used, should be fastened to the base.

3. *Construction of the Frame* (Fig. 1).—In the construction of the frame the use of ½-in. o.d. pipe welded in a box shape is suggested, with two horizontal rods on each of the four sides, top and bottom. The top rod should be at least 1 in. higher than the

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* Union Oil Company of California, Compton, California.

depth of the celluloid sections to be used. The bottom rod should be approximately ½ in. above the base, to allow clearance for the suspension of the celluloid sheets. The corner riser rods are threaded and flat screw-down heads are attached for mounting on the base.

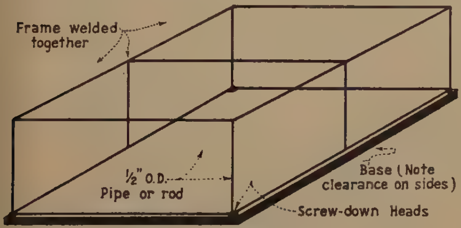

FIG. 1.—THE FRAME.

It is necessary to allow a clearance of 2 in. between the edges of the celluloid and the frame for the suspension of the sections. On these same sides, it is well to place additional risers and a horizontal rod at midpoint of the frame for bracing.

4. *Construction of the Spring Device* (Fig. 2).—A simple spring device for suspension of the sections within the frame may be constructed of the following: (1) one large-headed nail approximately 2½ in. long; (2) one compression spring 1½ in. long, large enough to fit over the body of the nail, but not the head; (3) a length of 14-gauge, stiff wire bent to shape as shown in Fig. 2.

Each suspension unit is assembled as follows: (1) place spring over nail, (2) bend pointed end of nail to act as a hook, (3) place wire around the nail below the spring, so that spring action is between the head of the nail and the wire, (4) adjust the spring compression by forming a hook on the free end of the wire for placement on the horizontal side members of the frame.

5. *Construction and Suspension of Sections* (Figs. 3 and 4).—On a model of this type the sections should be taken as nearly parallel as possible, and at right angles to the trend of the geologic features. If a deep-zone model is to be constructed, some shallow wells may have to be eliminated as sheet size and scale selected are the governing factors. In the choice of sections and wells to be used for interpretation, it is best to avoid long projections onto the line of section whenever possible.

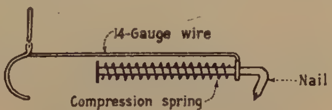

FIG. 2.—SPRING DEVICE.

Inexpensive work paper may be used for the initial layout of the sections. Original structural interpretations can then be worked out on these sections and traced onto the celluloid.

Well columns should be traced on one side of the celluloid sheet, using a double line column, with the producing intervals shown in solid color. The structural correlations are traced on the other side. This facilitates the changing of either structural interpretations or well status.

The use of India inks for all coloring is practicable, since it may be readily applied after the celluloid is powdered with draftsman's pounce.

Each celluloid section should be key-numbered in the upper corners to correspond with the lines of section on the base map. This facilitates model assembly and section revision. Holes should be bored in each corner for the placement of the suspension devices, spaced as follows:

Top holes: 1 in. from edge and top.

Bottom holes: 1 in. from edge and 3½ in. from bottom.

The celluloid sheets after suspension should rest against the base, since correct structural interpretation depends upon the maintenance of a constant subsea datum.

Cost

Cost of material for a model of 10 celluloid sections is as follows:

10 pieces of 60-gauge, noninflammable celluloid 20 by 48 in., at $5.50 per sheet.......	$55.00
Base....................................	2.50
Miscellaneous: frame, paint, springs, etc....	2.50
Total..............................	$60.00

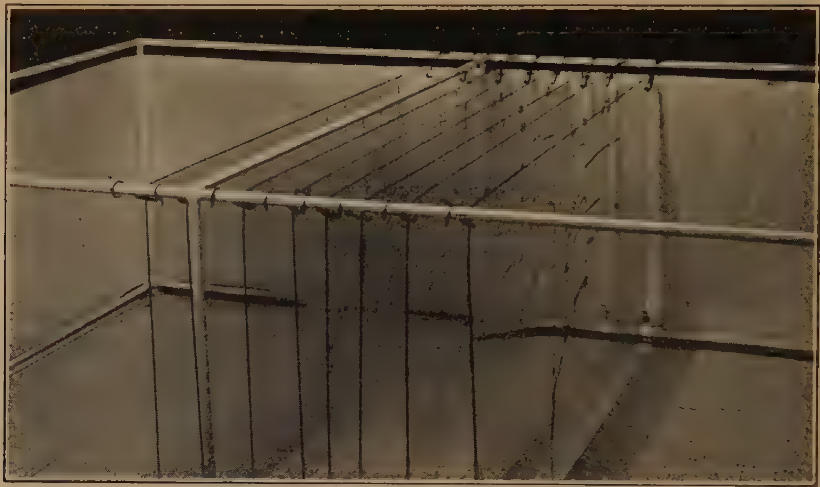

FIG. 3.—STRUCTURAL SECTIONS SUSPENDED WITHIN THE FRAME.

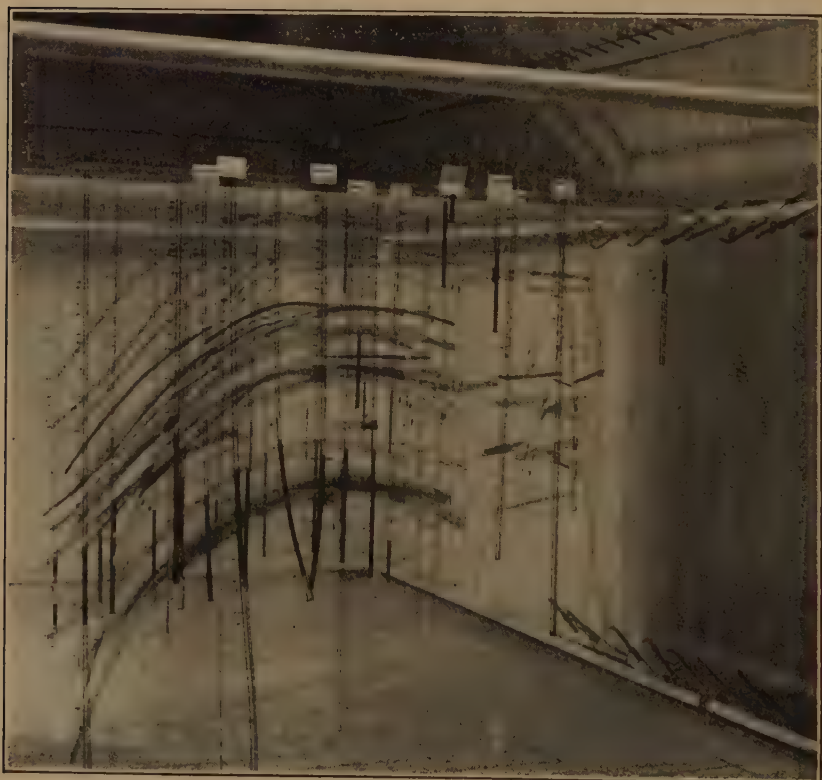

FIG. 4.—VIEW ALONG AXIS OF STRUCTURE, AS SEEN THROUGH A SERIES OF STRUCTURAL SECTIONS ON CELLULOID SHEETS.

Labor

The amount of labor involved in construction depends on the factual data available, the scale of the model, and the number of wells used. For example, a model with 10 sections showing deep-zone development in Dominguez field, using 61 wells, on a scale of 1 in. = 200 ft., was constructed by two men in two weeks, after all basic data had been assembled.

Use of Model in Solution of Structural Problems

As deeper zones were developed at Dominguez, it was discovered that the structure became more complicated with depth because of the presence of thrust faults. Thus, in contrast to the upper zones, in which oil and gas accumulation is controlled by anticlinal structure, that in the deeper zones is controlled by faulting. Typically the faults are south-dipping thrusts with decreasing throw as they are traced upward in the section. The importance of these faults was recognized when it was discovered that thrusts with less than 50 ft. throw controlled production between structural blocks. As a result, planning of the development program necessitated a detailed study of the subsurface geology of the field. This led to the construction of the celluloid model.

After the faults had been determined in individual wells, their location and amount of throw were plotted on the work sections. At this stage some of the more obvious faults could be connected and their traces followed from one section to another. However, there remained a number of faults in wells that could not be correlated. These were noted on the celluloid sheets. The sheets were then placed in the frame and a further effort was made to work out details of the faulting. This attempt was quite successful, although some of the fault trends could not be determined until the drilling of later wells gave additional points along the trace of the fault plane.

As each successive well is drilled, the formation correlations are plotted on the structural sections and in turn on the celluloid sheets. This takes but a short time and the model can be kept up to date with a minimum of effort.

It is not the purpose of this paper to advise the substitution of such a model for structural sections and contour maps, but to offer it as an aid in the development of fields possessing exceptionally complicated structure.

New Method of Plotting Slant Holes

By Tracy L. Atherton*

Drawings by Francis J. Hortig and C. L. Moore

(Los Angeles Meeting, October 1940)

The mapping of slant-hole oil fields is complicated by the fact that relationships between wells are subject to variations in three dimensions and are not readily adaptable to representation on a plane surface. Formalized perspectives usually expand into an undecipherable maze of lines and peg models with the necessary supporting dividers serve only to awe the beholder with their perplexity. The usual compromise arrived at is a plotting of the projection of the courses of all of the wells in the field onto a horizontal plane (Fig. 1). These complicated plots, when used in conjunction with the individual vertical projections of the wells, heretofore have been the most practical foundation for the study of general field problems. This method has many shortcomings, however, which are not found in the recently developed straight-hole equivalent projection method. The new method supplies a series of maps similar to the type now in common use in straight-hole fields. It is remarkably simple to use and supplies a ready check on clearances between wells. Perhaps the method can best be understood if the steps that led to its development are described.

Common practice of oil-well surveyors is to supply the owner with a tabling of the survey and a plan view plotted against the true meridian. If a vertical projection is plotted, it is usually plotted separately and shows vertical depths against the projection of the stations along a section line joining the top and bottom of the hole on the plan view. A more practical method would be to plot the section line of the plan parallel to the abscissa of the vertical projection (Fig. 2). If this is done, any line parallel to the "base line" will pass through the points on each projection that represent a single point in the hole. Another very useful graph, which the well surveyor could provide, would be plotting of vertical depths against measured depths.

Fig. 3 illustrates the next step facilitated by this form of plotting. The lines designated "well A" represent the proposed course of a hole to be drilled. Superimposed on the drawing, in its proper relative position, is the plan view and a portion of the vertical projection of a present producer, "well B." From an inspection of the plan view we arrive at the correct conclusion that the only indicated possibility of collision is at the point of crossing of the wells on the plan view. Referring to the vertical projection, note that the vertical depths of stations on B, in the vicinity of the crossing, are plotted on the same plane of projection as A. The clearance is the indicated distance between the two vertical sections measured along the parallel to the "base line," which passes through the point of intersection of the plan view. Repeat this process for the other wells crossing the proposed course of A on the plan view and you have a preliminary check of clearance for the proposed course. A similar comparison of crossings on the vertical projections of all

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wells whose plans approach within 50 ft. of A is next in order, and in the vicinity of the oil measures the comparison on both plan and vertical sections should be widened to include all wells within the predetermined minimum well-spacing distance. At best this is but a trial and error method, even though it does have the marked advantage of placing all of the data on a single sheet. Fig. 4 illustrates a map prepared for such a check.

FIG. 1.—PLAN VIEW OF A SLANT-HOLE FIELD.

The course of the hole as it is drilled can be plotted on the same sheet and further comparisons made as the drilling progresses. Maintaining an exact course would be prohibitive in cost and variation within a reasonable limit is common practice. This in turn requires that extensive portions of adjacent wells be plotted in order that the data be readily available for comparison. With the necessity to consider tolerances due to possible inaccuracies in well surveys, any approach of the drilling well on either the plan or vertical section necessarily has to be analyzed. In tight spots the proposition of looking at the situation from the top and then figuratively running around to one side to see how it looks from there is too inconclusive —what is required is the whole story in one picture.

The logical answer is to look at the situation from the point of view of the drilling bit; that is, plot the wells at their points of intersection with a plane constructed reasonably perpendicular to the drilling hole. The construction of such a projection is relatively simple if the proposed course is used as a guide (Fig. 5). The drilling well on the vertical section is 95 ft. above the proposed course and at the same point 10 ft. to the left of the proposed

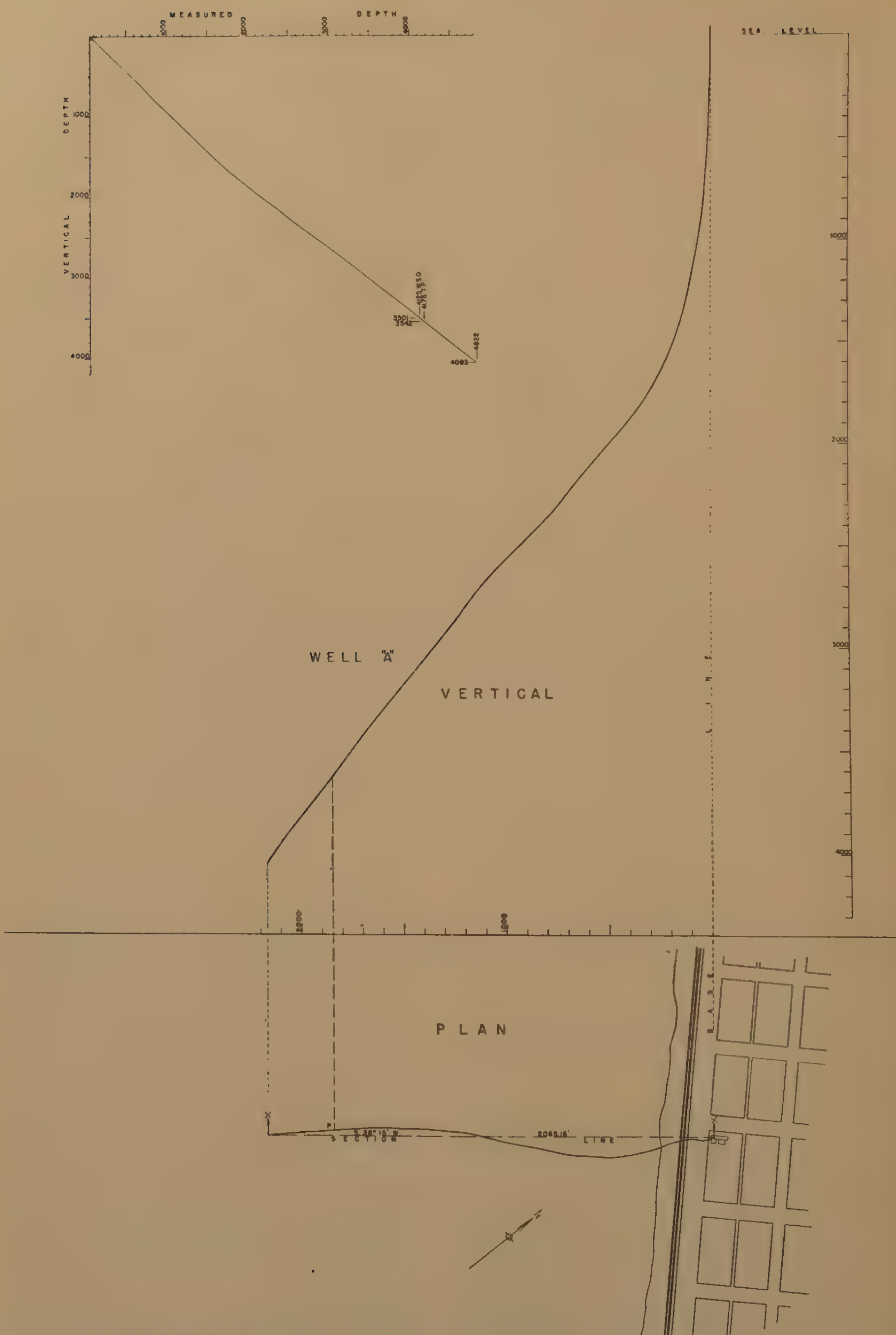

FIG. 2.—RECOMMENDED METHOD OF PLOTTING OIL-WELL SURVEY DATA.

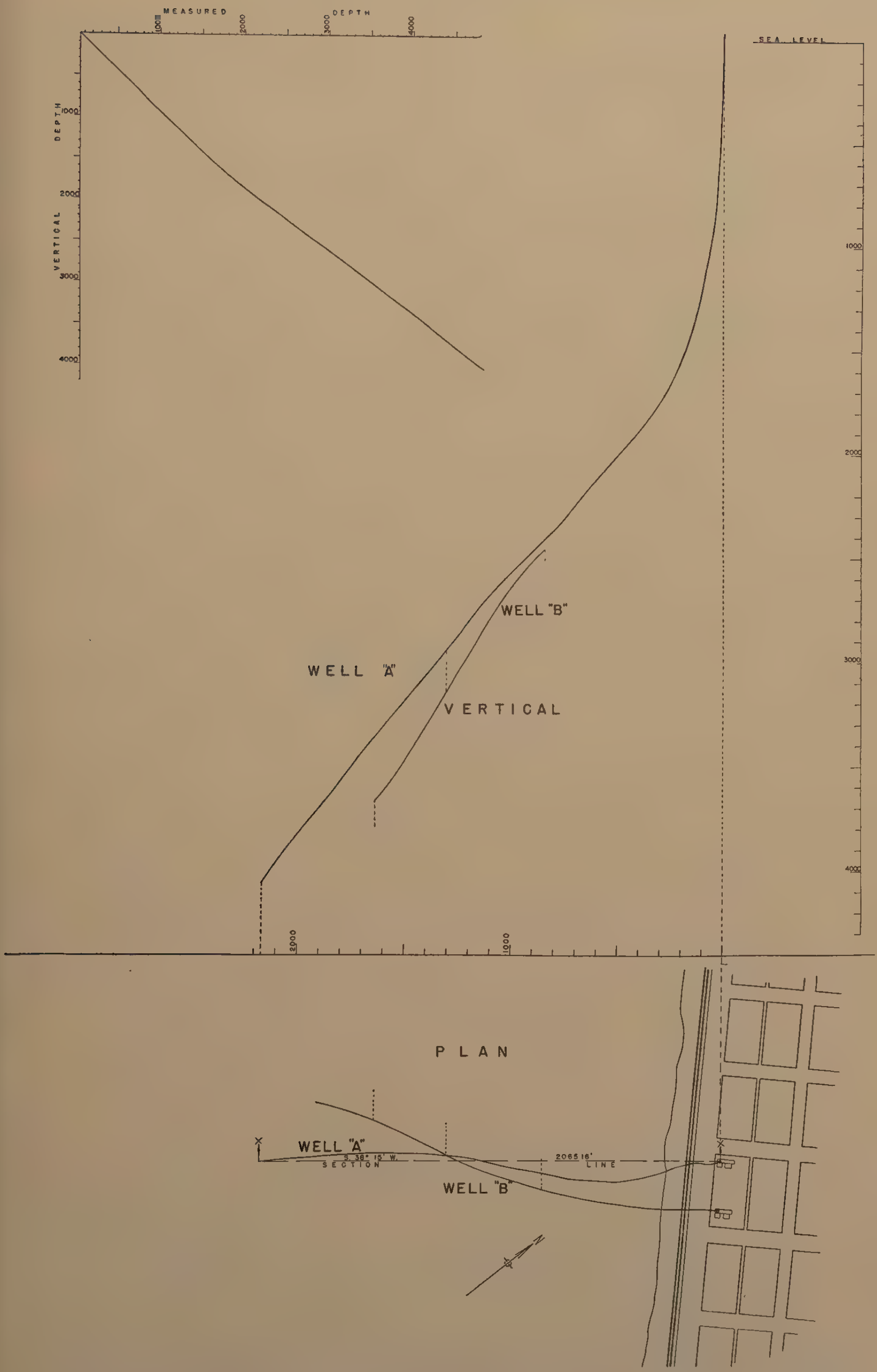

FIG. 3.—GRAPHIC REPRESENTATION OF AN ADJACENT HOLE ON THE RECOMMENDED PLOT.

FIG. 4.—GRAPHIC DEVELOPMENT OF ALL NEAR-BY WELLS ON THE RECOMMENDED PLOT.

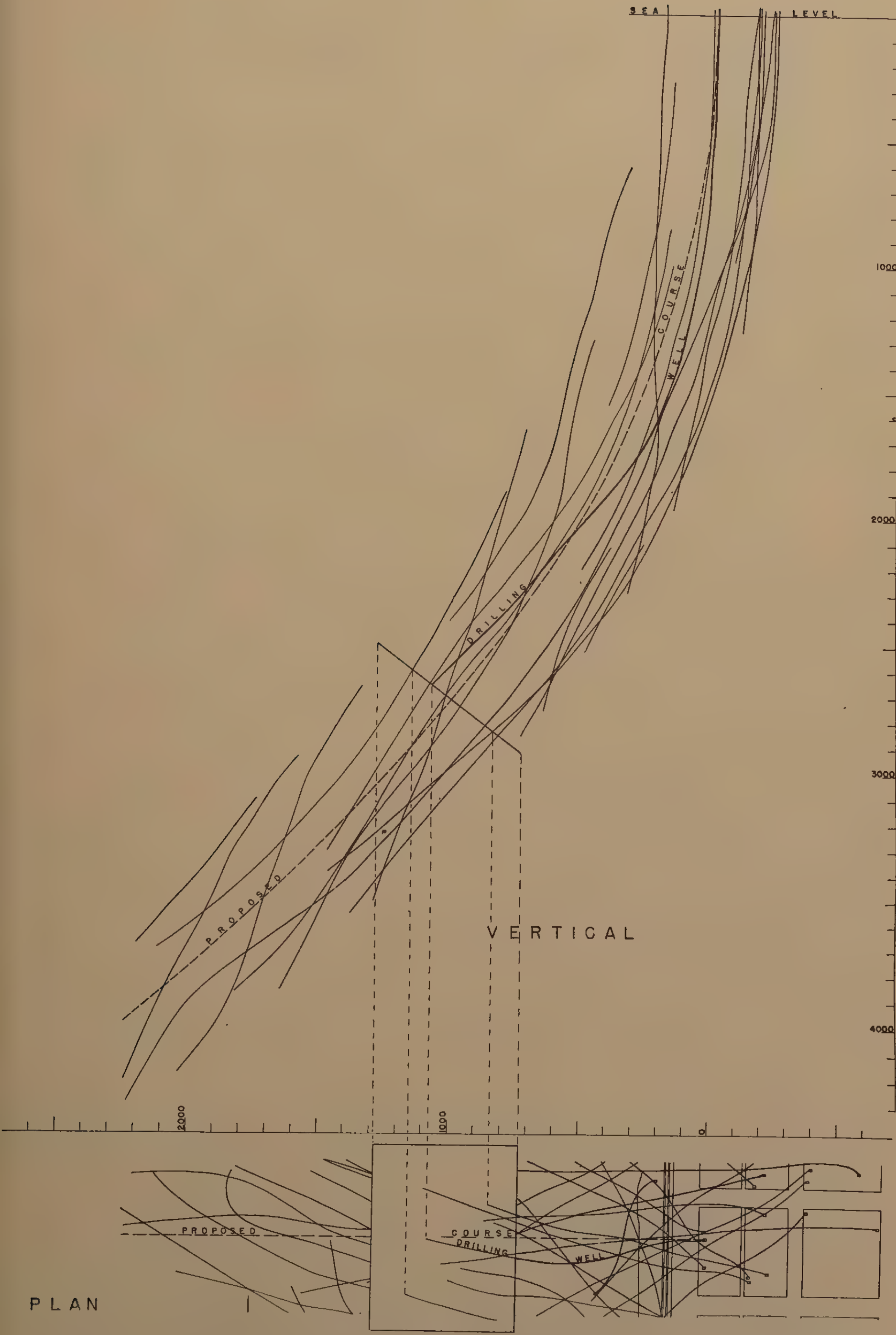

FIG. 5.—METHOD OF DEVELOPING SECTION AT POINT REACHED BY DRILLING BIT.

course. In the same fashion the location of the near-by wells may be determined with relation to the proposed course. Plotting these data gives the result shown by the circles in Fig. 6. Practical estimates of the clearance can be scaled directly from the plot.

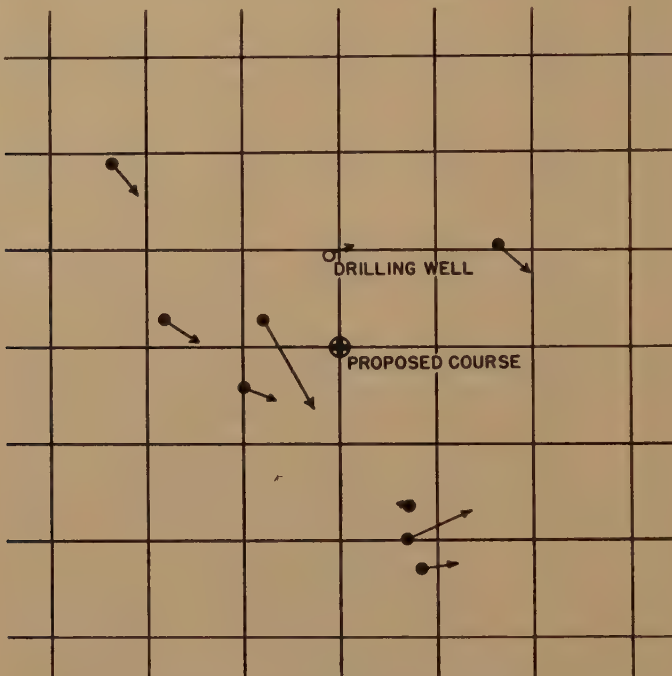

FIG. 6.—SECTION DEVELOPED AS ILLUSTRATED IN FIG. 5.

Presuming that this section was drawn at the last point reached by the bit, extend the drilling hole on both the plan and vertical projection and construct another section to show the anticipated clearances after the next 150 ft. has been drilled. Now superimpose the first section on the second, with the proposed course positions coincident, and the shift in relationship of any one hole with relation to the proposed course will be apparent. Arrows are drawn to show this shift and on a single plot the entire picture of conditions for the next 150 ft. is given.

Variations on the same theme will produce a connected chain of arrows for each well, each link representing the transition to the next of the series of planes; or, and this is the preferred plan, a series of sections similar to the one described above. If the latter are prepared on tracing sheets they can be laid over each other to obtain the chain of arrows and yet can be used singly to reduce confusion.

This briefly describes the evolution of the mapping process that led to the straight-hole equivalent sections. Obviously, it had paid its way by the rationalization of the problem of clearance in connection with drilling holes; but the real value of the principle lay in its application to the pool as a whole as a medium of facilitating a general study of well spacing and the formulation of an orderly plan for future development.

At Huntington Beach the tideland pool east of 23rd Street is tapped by a bank of 90 wells located within 900 ft. of the shore along a 4000-ft. front. The general direction

of the wells is perpendicular to the shore. A par hole, mathematically determinate, was computed and against it each of the wells in the pool were referenced as shown in Fig. 7.

The par hole was given a course perpendicular to the shore. The surface location was chosen so as to approximate the weighted average distance from the shore of all the slant-hole derrick locations. In vertical section, the par hole is a parabola with vertex at sea level, and a horizontal offset of 2000 ft. at 4000 ft. below sea level. This parabolic form was found to approximate closely the earlier wells drilled, though at present what might be termed a "railroad form" of tangents and circular curves is preferred. The choice of a parabolic vertical section facilitated the ready calculation of horizontal offsets, normals and tangents against vertical depth. Even the "measured depth," the length along the curve, can be computed with the aid of a 12-cylinder formula. "Measured depth" is a primary item in a well survey; but, even though these figures were calculated for the par hole, no important use has yet been found for them.

The plan and vertical sections of the par hole were then drawn as shown in Fig. 7. The normals to the par hole are shown on the vertical section—these are the traces of the straight-hole equivalent planes. Two typical wells, C and D, are also shown, plotted in proper relation to the par hole. In practice the plans and verticals of about 15 holes and the par hole with normals were plotted on a single sheet. When the number of lines on the sheet became confusing, a new sheet was started. Upon completion of the plotting, tabulations were made for each of the straight-hole equivalent sections; listing for each section: (1) from the vertical projection, the distance, measured along the trace of the section, of each well above or below the par hole (indicated as C_v and D_v), and (2), from the plan, the distance right or left of the par hole of the point of intersection of each well with the designated section (indicated as C_H and D_H).

Each straight-hole equivalent section is then plotted from the tabulated data against the par hole. Since on each section each well is correctly represented in relation to the par hole, each well is correctly represented with relation to every other well. Superimposing the section over the next section below, making the par holes coincident, an arrow is drawn from the well on the upper section to the position the same well occupies on the lower section. Each arrow represents graphically, by length and direction, the movement of a well relative to the par hole in passing to the next section.

Practical Results

Fig. 8 is a straight-hole equivalent section in the easterly end of the Tideland pool at Huntington Beach. The par hole on this section is at a vertical depth of 3400 ft. below sea level and about 1000 ft. seaward of the shore line. If the top of the drawing is raised until the sheet makes an angle of 40°22′ with the table, the observer's eyes will approximate relatively the surface location of the wells.

Any new holes drilled will be reasonably perpendicular to the section. If an arbitrary drainage radius of 200 ft. in the oil sand is adopted, measured in the plane of the section, the possibility of new locations is evident. These new locations are indicated tentatively and then checked through the lower sections against the possibility of pinching out, and are then plotted on the horizontal and vertical projections to see that they satisfy practical drilling requirements. When surface locations are selected for the new bottoms, tentative horizontal and vertical courses are laid out and tested on the straight-hole equivalent sections. In a surprising number of instances revisions in the courses are necessary to assure a predetermined minimum clearance for

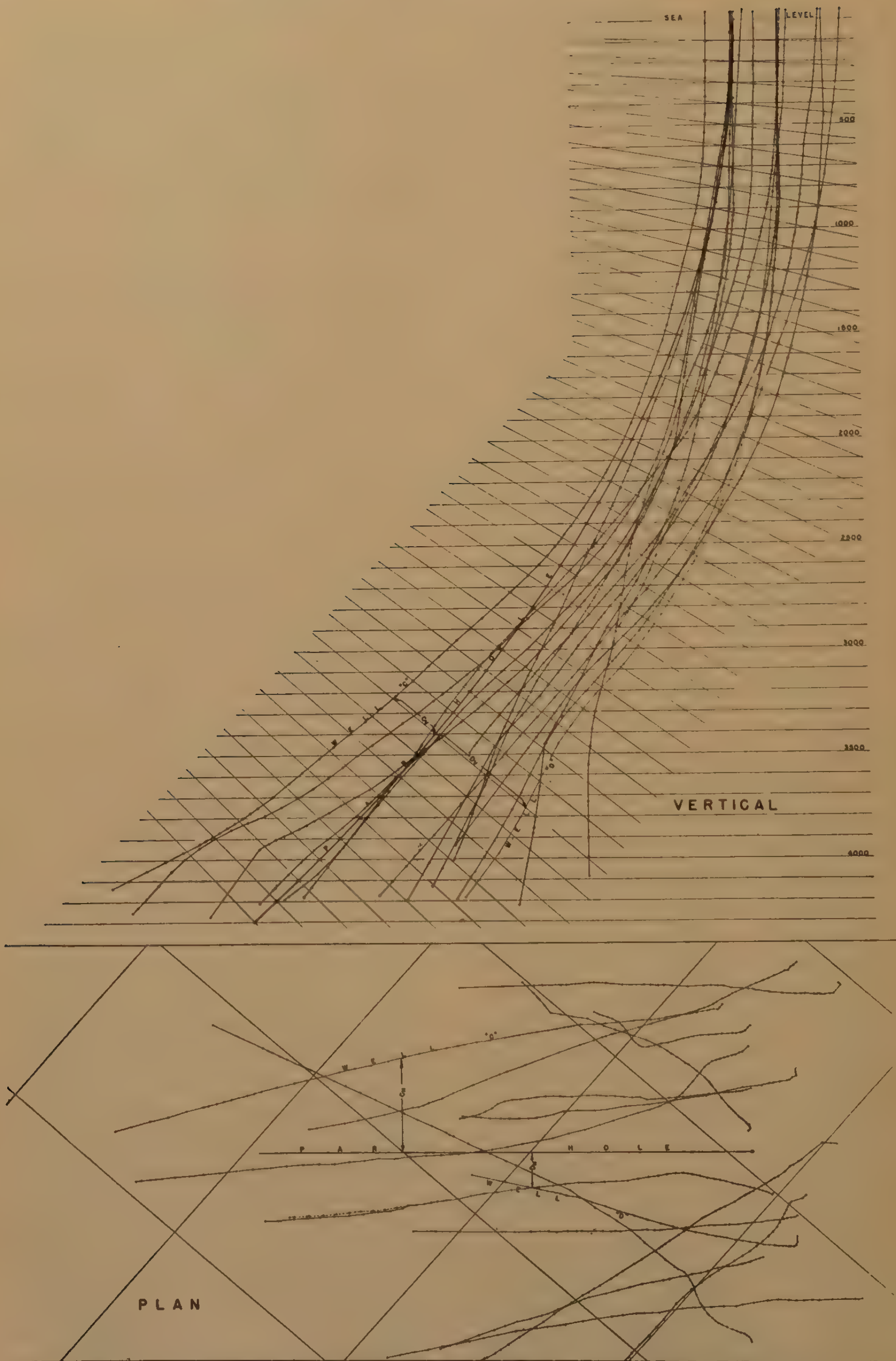

FIG. 7.—METHOD OF DEVELOPING STANDARDIZED SECTIONS AGAINST A PAR HOLE.

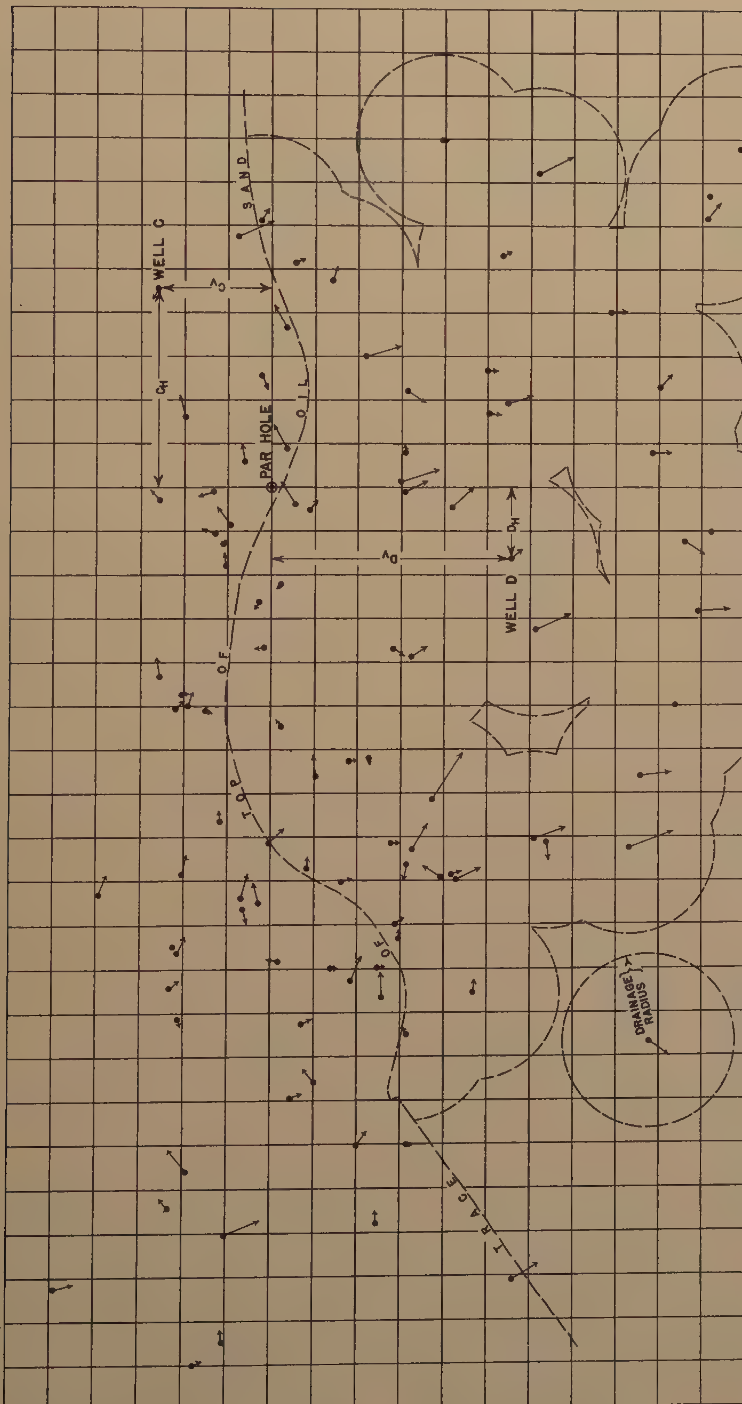

FIG. 8.—COMPLETE STRAIGHT-HOLE EQUIVALENT SECTION FOR FIELD, DEVELOPED AGAINST A PAR HOLE.

wells in place. When drilling is under way clearances are checked upon the sections as the well progresses.

The sections also are very helpful in directing the best course for redrilling in order to avoid collision, provide better spacing for drainage and minimize the possibility of damage to other wells.

The method is quite workable in operation and the sections provide a relatively simple map for laymen. While the application described here was tailored for the Huntington Beach Tideland pool, the primary principle, of mapping perpendicular to the hole, will simplify many slant-hole mapping problems.

Development and Application of Subsurface-pressure Data in Kettleman Hills

By E. W. McAllister*

(Los Angeles Meeting, October 1940)

The decision of the California Oil Umpire's[1] office to accept well potentials established from subsurface-pressure data has brought to the attention of many operators for the first time the application of such data to production problems. This paper reviews the development and application of subsurface-pressure data in Kettleman Hills, where these data have been used in production work since 1932.

The Kettleman Hills field was discovered in October 1928. The first subsurface-pressure surveys were made early in 1932 and by the middle of 1933 the two major operators in the field were making routine pressure runs in their respective wells. Shortly thereafter, these companies agreed to exchange pressure data, and later a third company entered into the agreement. This made it possible to analyze the effects upon the reservoir pressure of past production practices, which are discussed in the latter part of the report.

It is interesting that many of the applications of subsurface-pressure data discussed herein were anticipated by C. L. Clark† and C. B. Kimberlin‡ in a report[2] dated March 1933.

Productivity Index

In the majority of individual well problems involving the use of subsurface-pressure data, it is necessary to use a factor known as the "productivity index," which indicates the ability of a well to produce and represents the number of barrels of oil or oil and water per day that will enter the well bore for each pound per square inch pressure drop made opposite the producing interval of the well. The productivity index may be determined from pressure and production data for one or more rates of flow and a static or shut-in pressure survey or from production and pressure data for two or more rates of flow. Productivity indices may be based upon either net oil or total fluid production. All indices referred to in this report are based upon net oil.

The value of the productivity index for Kettleman Hills wells decreases generally with time and it is not uncommon for the index to vary in value at any specific time for various rates of flow. The decline of the productivity index may be attributed partly to the loss of reservoir pressure. As the reservoir pressure decreases, gas originally in solution is released from the oil, congesting the flow of fluids through the formation and increasing the viscosity and surface tension of the oil; thus the flow resistance of the fluids through the formation is increased, resulting in a decrease of the productivity index. For convenient reference, the productivity indices for each well are plotted against time and a curve is drawn through the points showing the trend of the average index value. Plotted on Fig. 1 are index values for five

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[1] References are at the end of the paper.

† Formerly with Kettleman North Dome Association.

‡ With Kettleman North Dome Association.

different wells represented by the various symbols.

STATIC-PRESSURE SURVEYS

Static-pressure surveys are made after a well has been shut in for 24 hr. or longer, if necessary to obtain a maximum pressure build-up. The rate of pressure build-up in gas wells or wells of high gas-oil ratio is usually faster than in wells of low gas-oil ratio.

Static-pressure runs are made generally in conjunction with one or more flow-pressure surveys and serve a twofold purpose: (1) the calculation of productivity indices; (2) the determination of reservoir pressures at a datum plane for pressure correlations between areas and zones and the plotting of subsurface-pressure maps. For pressure correlation work at Kettleman Hills, a datum plane of 7000 ft. below sea level is used for the Temblor zones and 10,000 ft. below sea level for the Eocene zone. These depths were selected because they fall within the producing interval of most of the wells in the zones concerned.

Examples of reservoir-pressure decline of Temblor wells in the various areas of the field are shown on Fig. 2.

GRADIENTS

Flow gradients or pressure loss in the flow string (Fig. 3) are determined from pressure traverses made in flowing and gas-lift wells. The gradients are determined for various rates of oil production, gas-oil ratios, surface back pressures, and tubing sizes. These data are of especial value in potential calculations and gas-lift problems.[3]

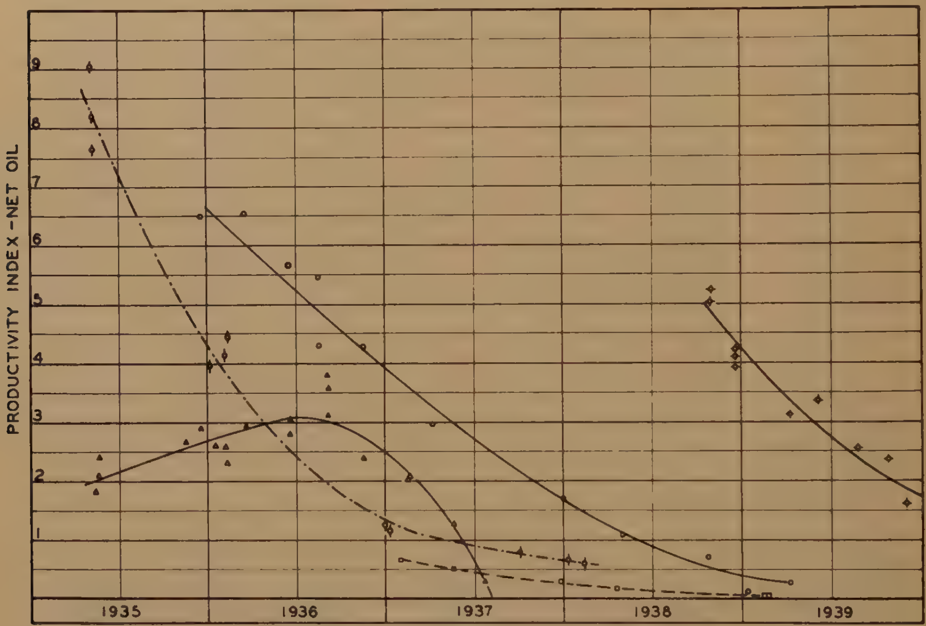

FIG. 1.—PRODUCTIVITY-INDEX DECLINE.

POTENTIALS

The potential of a well, determined by the use of subsurface-pressure data, is equal, theoretically, to the product of the productivity index and the maximum mean pressure drawdown that can be made opposite the producing interval of the well. By maximum mean pressure drawdown is

meant the mean pressure difference opposite the producing interval of the well between the static or shut-in pressure and the minimum flow pressure that can be obtained under the conditions for which the potential is to be calculated. A graphic determination of the potential of a well from subsurface-pressure data is shown on Fig. 4. Curve 1 is plotted from a static-pressure survey made in a well that had been shut in for 30 hr. Curves 2 and 3 are plotted from flow-pressure runs made in the same well producing at the daily rates of production with pressures as shown in Table 1.

TABLE 1.—*Potentials from Subsurface-pressure Data*

	Curve 2	Curve 3
Oil, bbl. per day	2523	4333
Water, bbl. per day	174	199
Gas, M cu. ft. per day	3496	6340
Tubing pressure, lb. per sq. in.	350	710
Casing pressure, lb. per sq. in.	1130	280

The highest demonstrated production rate of 4333 bbl. per day (curve 3) was the maximum production that could be handled with the surface equipment available.

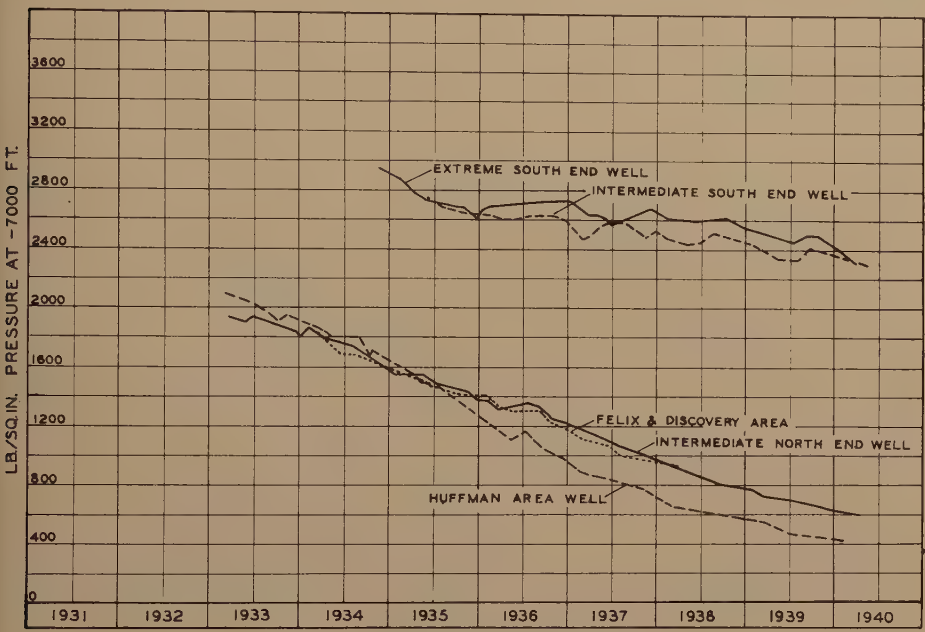

FIG. 2.—RESERVOIR-PRESSURE DECLINE.

Productivity indices calculated from the static-pressure survey and pressure and production data of curves 2 and 3 were 3.58 and 3.44 bbl. per pound per day, respectively.

The atmospheric potential or the maximum production of the well at atmospheric surface pressure was determined by plotting a theoretical pressure traverse, curve 4, starting at zero pounds surface pressure and using the same average flow gradient as that of curve 3. This in effect assumes an additional pressure drop at the bottom of the hole equivalent to the surface producing pressure of curve 3, or 280 lb. Multiplying 280 lb. by the productivity index of 3.44, calculated from the highest demonstrated production rate, indicates a theoretical increase in production of

963 bbl. per day, or an atmospheric potential of 5296 bbl. per day (4333 + 963 bbl.).

Additional surface equipment was installed at this well a few days later and an out the flow string, permitting the release of additional gas from solution and the increased expansion of the free gas that results in greater aeration or lightening of

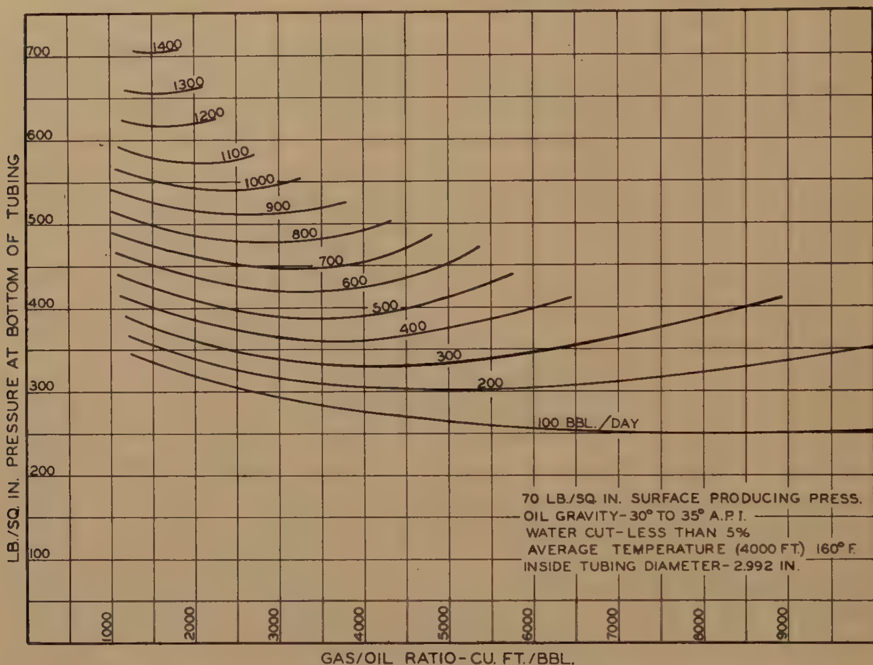

FIG. 3.—PRESSURE AT BOTTOM OF 8000 FEET OF 3-INCH TUBING FOR VARIOUS RATES OF FLOW.

actual potential of 5466 bbl. per day was demonstrated.

In the preceding potential calculation, it was considered reasonably accurate to plot a flow-pressure traverse, curve 4, using the same average flow gradient as the pressure traverse of the highest demonstrated rate, curve 3, because empirical flow-gradient data indicated that the gradient of 0.082 lb. per foot for curve 3 was a minimum value to be expected for the production rates of oil and gas concerned.

In general, in wells having low gas-oil ratios, the flow gradient becomes less, denoting less pressure loss in the flow string, as the production rate is increased. This is due to the reduced surface pressure at the higher rates of flow being reflected through the fluid column. In determining potentials for large wells from small demonstrated production rates, this lightening effect must be taken into account for accurate potential determinations.

Potential Decline

The potential decline of a well is a result of reservoir pressure loss and loss of productivity as indicated by the decline of the productivity index or a combination of both. On Fig. 5 are plotted data selected for their uniformity, showing the decline of the reservoir pressure and the productivity index of a Kettleman Hills well. A loss of potential is represented by the decline of either curve and the combined decline of both curves represents the "absolute" potential decline of the well.

By "absolute" potential is meant the potential of a well assuming all pressure could be removed from the face of the producing sand. The "absolute" potential is equal theoretically to the product of the productivity index of the well and the static reservoir pressure at any specific time.

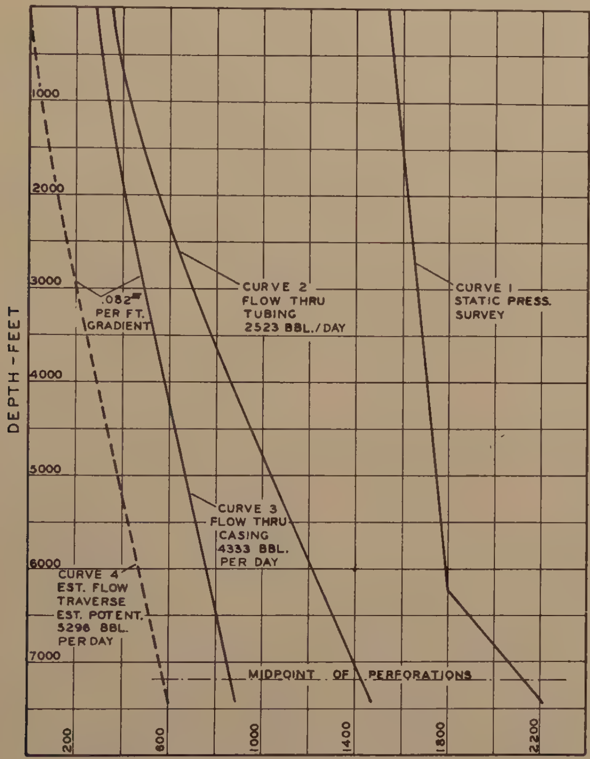

FIG. 4.—POTENTIAL DETERMINATION.

Plotted on Fig. 6 is the absolute potential decline for the well data as shown on Fig. 5. Inasmuch as it is not possible to produce the absolute potential (i.e., remove all pressure from the face of the sand) in large wells until the latter period of the life of the well, plotted on the graph also are the producible potentials for 500, 150, and 60 lb. per sq. in. surface pressures and the actual daily average production rates by months produced during the life of the well at the various surface back pressures. The approach of the actual production of the well to the absolute potential during the first part of 1940 was caused by: (1) the installation of equipment for producing the well by intermittent gas lift, thus increasing the production over that which could be obtained normally by straight gas lift at low rates of flow, and (2) the probable increase of the potential of the well due to the repressuring effect of approaching edge water, as evidenced by the increase in static pressure in 1940 (Fig. 5) and by an increasing well cut.

Well-potential decline curves, such as are shown on Fig. 6, usually are straight lines or nearly so (denoting constant percentage decline) when plotted on semilogarithmic paper; hence it is not a difficult matter to extrapolate safely the potential

declines for reasonable periods into the future once the trend of the curves has been established.

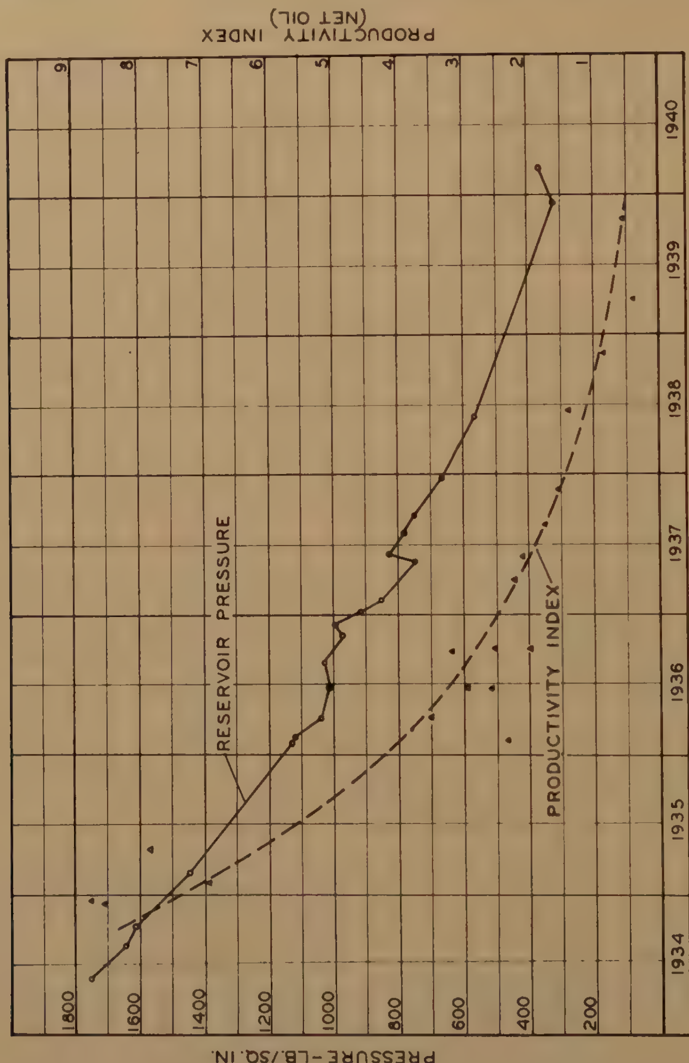

Fig. 5.—Pressure and productivity, individual well.

to maintain a 60-lb. per sq. in. (surface producing pressure) field potential, considered high enough to take care of any

Applications of Subsurface-pressure Data

Development Program

In developing the field, it has been the policy of the Kettleman North Dome Association to complete only enough wells irregularities that may occur in the normal field potential decline, minor fluctuations in the field production rate, and sufficient flexibility to adjust for varying gas demands.

To facilitate the determination of the number of drilling strings necessary, a

potential-decline curve for the field is plotted, based on individual well-potential declines calculated from production and subsurface data as described previously.

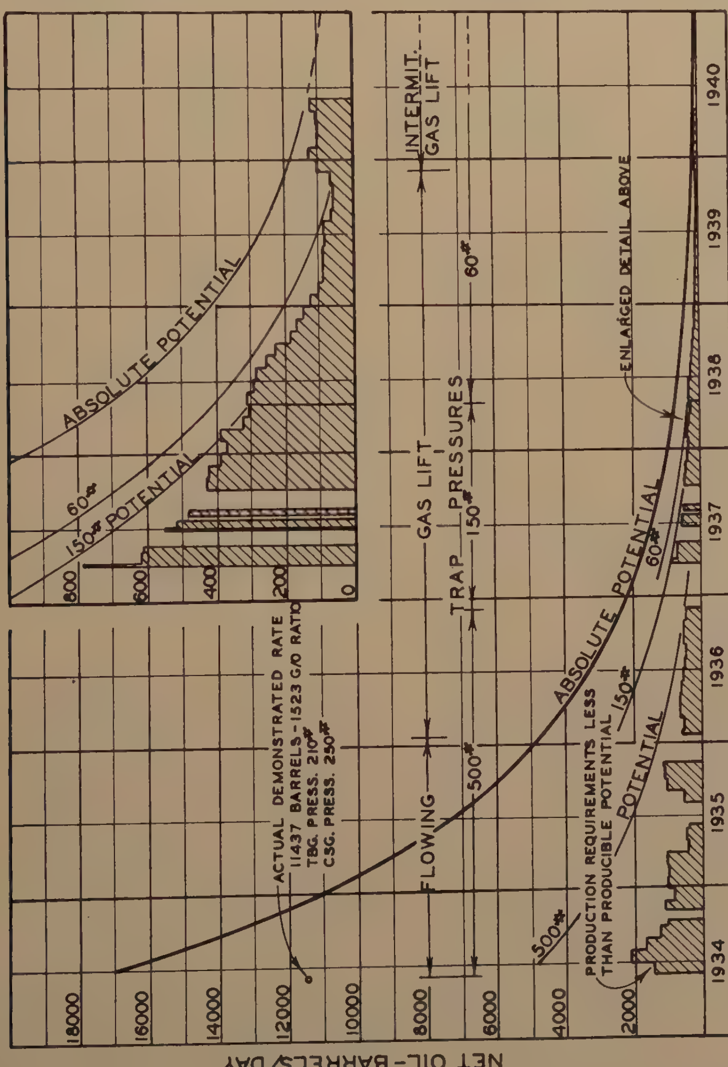

FIG. 6.—POTENTIAL DECLINE, INDIVIDUAL WELL.

Superimposed on this curve are the expected increases in potential from future completions for various numbers of drilling strings. From these curves the drilling program that will maintain the field potential desired is then selected.

Surface Facilities

Originally all wells were produced at at least 500 lb. surface pressure. This pressure was necessary in order to take care of pressure losses through the gas-gathering lines and absorption plants and to deliver the gas at the required pressure directly to the utility companies.

As the subsurface pressure declined with the attendant loss in production, it became

necessary to build gas-gathering systems of 125 lb. and 60 lb. per sq. in. pressure, so that the producing pressure at the wells could be lowered in order to maintain the field production. This, of course, required the construction of plants for compressing the gas so produced to the required 500 lb. pressure per square inch.

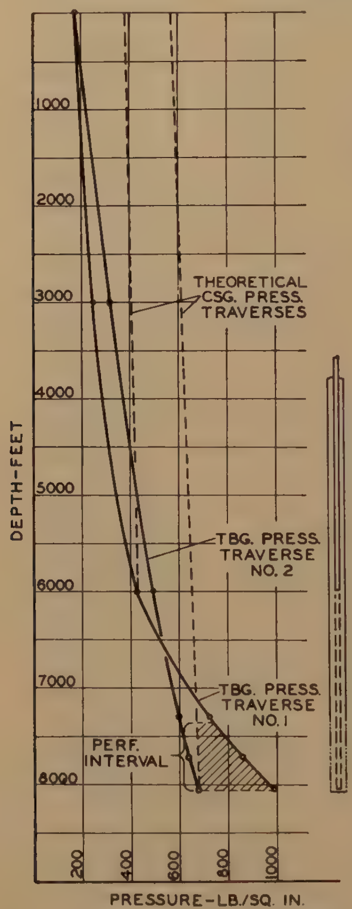

FIG. 7.—TYPICAL GAS-LIFT CURVES.

In planning the installation of these facilities, it was necessary to make estimates of the volumes of gas to be handled at the different pressures and from which areas the gas would be produced. This was done by determining the potential oil decline of the individual wells at the various surface producing pressures by plotting curves similar to those shown on Fig. 6. From these curves the approximate times at which it would be necessary to reduce the surface producing pressure of the individual wells were determined and the approximate volumes of gas to be handled were calculated by multiplying the expected oil production by the gas-oil ratio of the well. The trend of the gas-oil ratio was obtained from production curves such as usually are kept by all companies.

Gas Lift

Subsurface-pressure data are indispensable in the solution of gas-lift problems relating to tubing depths, surface and subsurface producing pressures, and the advisability of various types of equipment installations.

The pressure traverses on Fig. 7 illustrate the use of subsurface-pressure data in problems pertaining to tubing depths in gas-lift wells. The curves were plotted from flow-pressure runs made in the same well under different conditions.

Pressure traverse No. 1 indicated that by lowering the tubing below its original depth of 6018 ft., and thus making it possible to aerate the flow column from a point lower in the well, a reduction in operating pressure against the producing sand would be effected. The magnitude of the possible decrease in pressure and the productivity index indicated that this would result in a substantial increase in production.

Pressure traverse No. 2 was made after the tubing had been lowered to 8022 ft. The subsequent decrease in operating pressure against the producing interval is shown by the shaded area on Fig. 7. The increase in pressure loss through the tubing for traverse No. 2, as evidenced by the difference in pressure of the two traverses at 6000 ft., is due primarily to the increased friction loss through the tubing caused by the greater velocity of the higher rate of flow. The production data for the times

when the pressure surveys were made are as shown in Table 2.

It may seem that the pressure surveys were unnecessary and that by simply lowering the tubing an increase in production would have been obtained, which is true in the example cited. However, there are numerous cases in which the pressure surveys indicate that there will be little advantage gained in lowering the tubing because of the already lightened flow gradients below the tubing or because the probable decrease in operating pressure, coupled with a low productivity index, will result in little increase in production; hence, unprofitable tubing jobs are averted.

The pressure traverses on Fig. 7 show that when the tubing was lowered the surface casing pressure increased from 380 to 570 lb. per sq. in., owing to the increased flow-pressure losses through the additional tubing and the higher rate of flow. Thus, the approximate tubing depth for specific surface conditions may be predetermined graphically by the intersection of theoretical casing-pressure and tubing-pressure traverses plotted starting with the surface pressures desired.

On Fig. 8 are shown time-pressure relationships and oil production for three types of intermittent gas-lift equipment. Curves of this nature are especially helpful in analyzing the operation and advantages of the various types of intermitting gas-lift devices. Allowing for the surface producing pressure of 75 lb. per sq. in., the minimum points of the curves indicate that there is still considerable pressure remaining against the formation. This is not consistent with

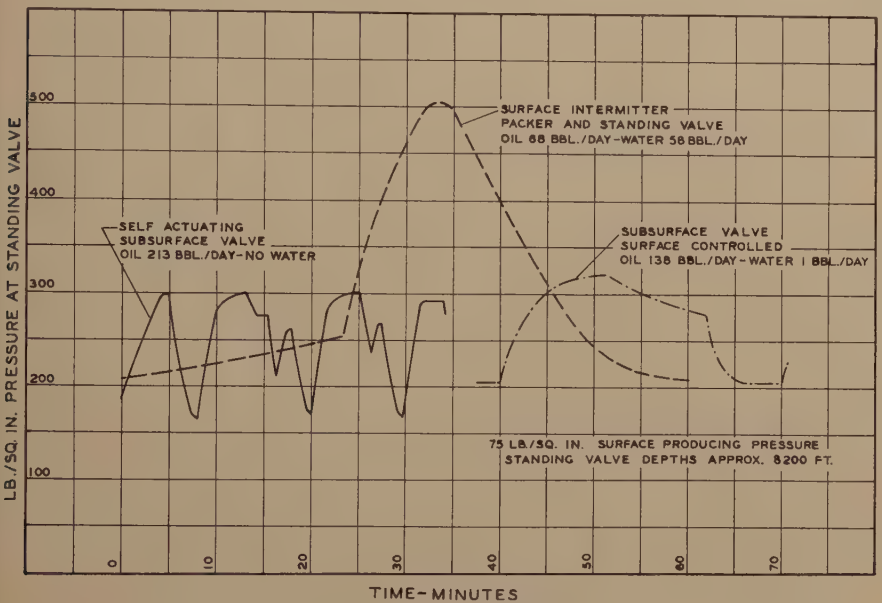

FIG. 8.—PRESSURE-TIME CURVES, INTERMITTENT GAS LIFT.

TABLE 2.—*Production Data for Pressure Surveys*

	Traverse No. 1	Traverse No. 2
Date	11-3-37	1-4-38
Oil, bbl. per day	535	918
Water, bbl. per day	13	11
Formation gas, M cu.ft. per day	231	673
Circulated gas, M cu.ft. per day	700	1378
Tubing pressure, lb. per sq. in.	170	180
Casing pressure, lb. per sq. in.	380	570

claims of many of the equipment manufacturers. However, in wells of small production rates, intermittent gas lift is more efficient than straight gas lift and generally results in an increase in production over that obtained by straight gas lift.

Use of Formation Pressure Data for Precise Analysis of Effects of Production Practices upon Reservoir Pressures

Prior to the development and use of subsurface-pressure recorders, reservoir pressures were a matter of conjecture based principally upon the characteristics of the well as evidenced by production rates, surface pressures and fluid levels. Because of varying flow conditions, as affected by changing gas volumes and producing pressures, and the lack of knowledge regarding productivity indices, it was impossible to determine accurately from such data subsurface-pressure conditions that actually existed; hence, little was known or suspected as to the magnitude or the extent of the effect of various production practices upon the reservoir.

At Kettleman Hills, however, 8 years of actual subsurface-pressure history have made it possible to show specifically the effects upon the reservoir of past production practices in this field. It is believed no other field offers a better example of production methods affecting a field adversely than does Kettleman.

The Kettleman North Dome Association was organized early in 1931 to operate under a unit plan leases held by 14 companies on approximately 49.6 per cent of the 16,730 productive acres of the field. The Standard Oil Company of California owns approximately 47.2 per cent of the field acreage and the remaining acreage, 3.2 per cent, in two separate areas, is divided among six companies. These areas with the adjacent Standard and Association properties are known as the Huffman and Felix areas and are outlined with other areas on the maps shown on Fig. 9.

The major part of the production of the field has been concentrated in the Huffman and Felix areas, because the operators of the small leases in the Huffman and Felix areas agreed only to an intrafield allocation of the production of the field as set by the Oil Umpire on an inequitable well basis, or set arbitrary production rates below which they would not go. Thus, these properties were produced consistently at rates higher than would have been allocated to them on the more equitable basis of productive acreage. For example, during the first nine months of the Association's existence, April 1 to Dec. 31, 1931, the competitive properties, comprising 3.2 per cent of the productive acreage of the field, produced an average of 17,964 bbl. per day, or 35 per cent of the average production of the field of 51,318 bbl. per day. This left the Standard and Association 65 per cent of the production allocated to the field, or less than twice that allocated to the competitive properties.

Similarly, during the subsequent years the competitive properties, by one method or another but owing primarily to their threat to overproduce anyway if a smaller share of the allotment of the field were assigned them, were allocated inequitable percentages of the field production, until by the beginning of 1940 they had produced more than 39 million barrels, or 17.9 per cent of the total production of the field of approximately 220 million barrels of oil. Consequently, until the competitive areas had declined sufficiently, it was necessary for the Standard and the Association to utilize the greater part of their allocated production in attempting to protect their immediately offsetting properties in the areas having approximately five times the acreage of the competitive leases.

The forced concentration of the production of the field in the competitive areas resulted in the rapid decline of their reser-

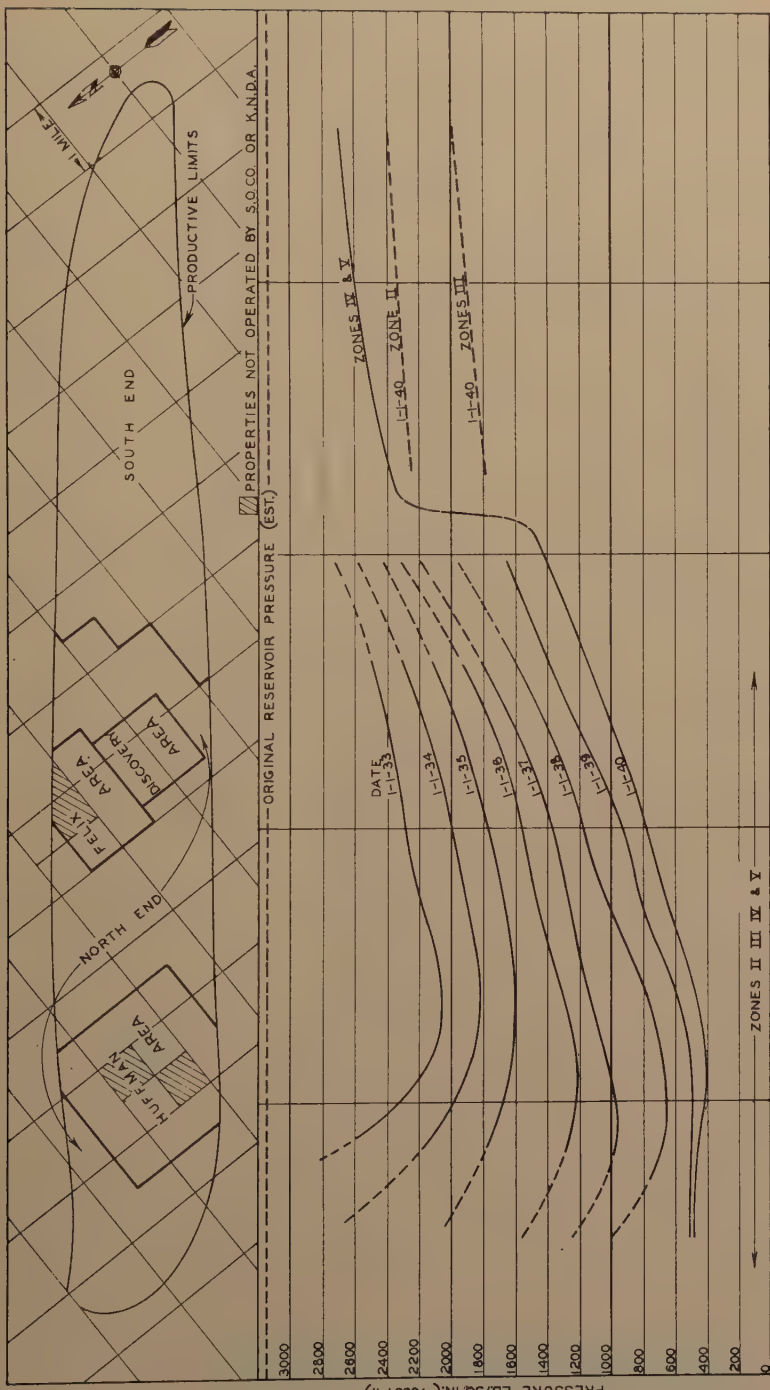

FIG. 9.—LONGITUDINAL PRESSURE GRADIENTS THROUGH FIELD, TEMBLOR ZONES.

voir pressures and the subsequent expansion of the gas cap to these areas. The attendant increase in gas-oil ratios only aggravated the already undesirable situation. The effects of producing the field in this manner were far reaching. Pressure declines were experienced not only in all properties in the northwest half of the field, where the competitive areas are located, but also in the extreme southeastern parts of the field, from which, until recently, there had been little or no production.

On Fig. 9 are plotted the yearly reservoir-pressure gradients along the longitudinal axis of the field, showing the present "unbalanced" condition of the reservoir pressure due to the concentration of production in the competitive areas in the northwest end of the field. The original reservoir pressure of the northwest end of the field has been depleted more than 75 per cent and the created pressure differential between the two ends of the field has resulted in drainage, which has reduced 25 per cent or more the reservoir pressure of the southeast end, from which less than 4 per cent of either the gas or oil production of the field has been removed.

Fig. 9 shows also that all properties in the northwest end of the field have been depleted of reservoir pressure to approximately the same degree, regardless of differences as great as five to one in oil recovered per acre from the various properties favorably located outside the gas cap. This depletion of pressure has left the remaining oil in all northwest properties relatively inactive (denuded of gas originally in solution) and has caused migration to areas of low pressure or into the undrilled gas cap, which has led to low recoveries from all properties outside the competitive areas.

This situation illustrates the inequities of basing the allocation of the allotment for the field upon the number of individual wells and their ability to produce without consideration of the proven acreage of the field and the oil in place. In other words, the operators having small leases which they were able to develop early, were, on a well basis, allocated percentages of the field production not consistent with the acreage of their properties.

Similarly, the state-wide curtailment program connotes the same inequities; fields of noncompetitive or semicompetitive nature, such as Kettleman Hills, are penalized for maintaining an orderly plan of development and a uniform plan of well spacing consistent with the reservoir reserves, while highly competitive fields increase their allotment by rapid drilling on well spacings of much greater densities.

The cumulated net oil and gas production plotted by years for the field and for the various areas are shown on Figs. 10 and 11. The percentages on the curves at the end of each year are the percentages of the total cumulated field production of each area at the end of the year in question. For example, on Fig. 10, the Huffman area had produced 47.6 per cent of the total oil removed from the field at the end of 1939, while at the end of 1936 this area had produced 52 per cent of the total cumulated field production. The percentage circles on the graphs show the breakdown as to areas of the total oil and gas produced from the field for any one year. For example, the 1939 percentage circle on Fig. 10 indicates that the Huffman area produced approximately 25 per cent of the total oil removed from the field during this year, while in 1937 this area produced more than 50 per cent of the oil production of the field. The areas of the percentage circles in relation to each other are proportional to the production of the field for each year. The potential decline of the competitive areas and the subsequent transfer of production to other areas can be noted on the percentage circles.

Referring again to Figs. 10 and 11, of the 220 million barrels of oil and 1200 billion cubic feet of gas produced by the end of 1939 from the Temblor zones of Kettleman

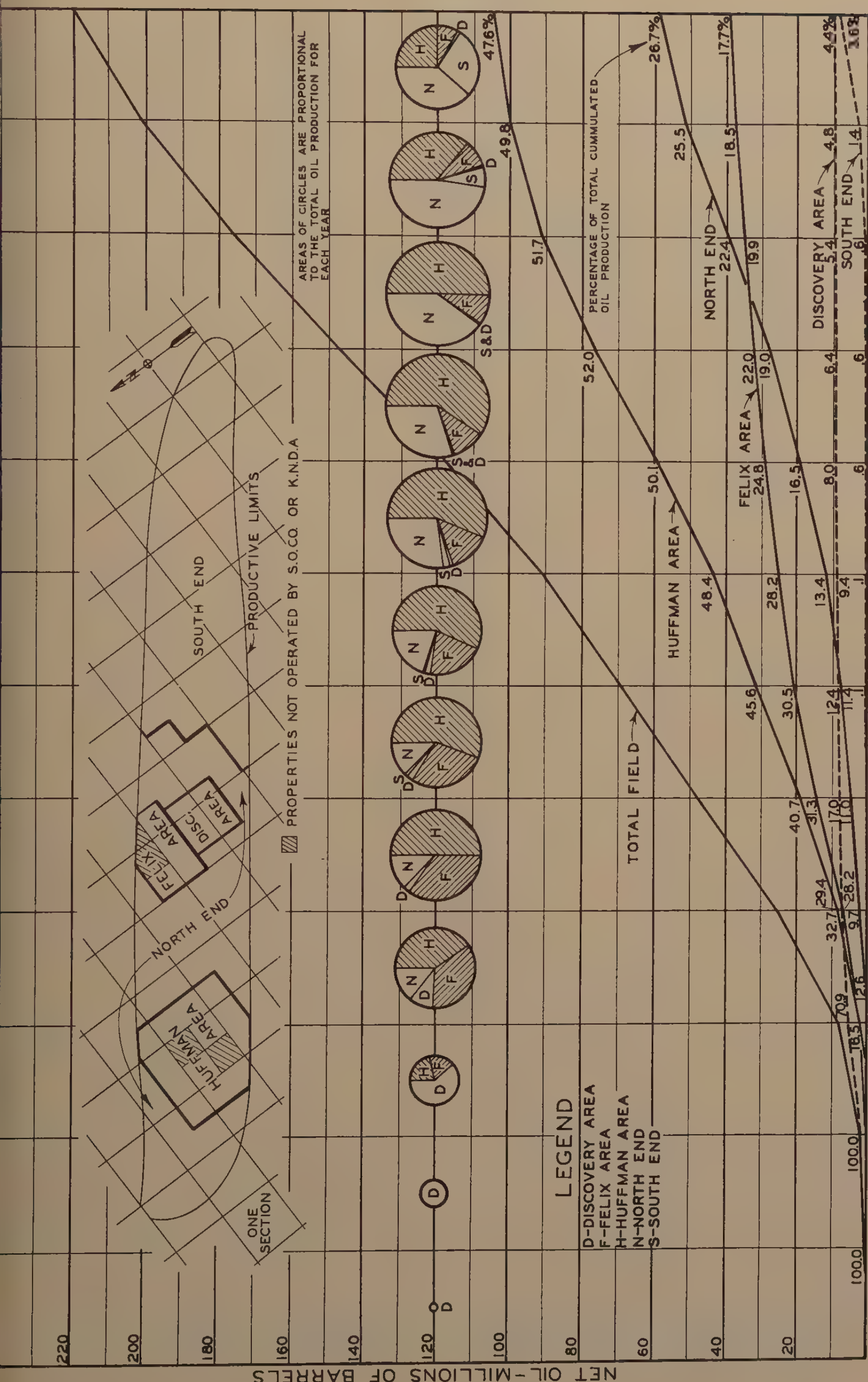

FIG. 10.—CUMULATED OIL PRODUCTION, KETTLEMAN NORTH DOME, TEMBLOR ZONES.

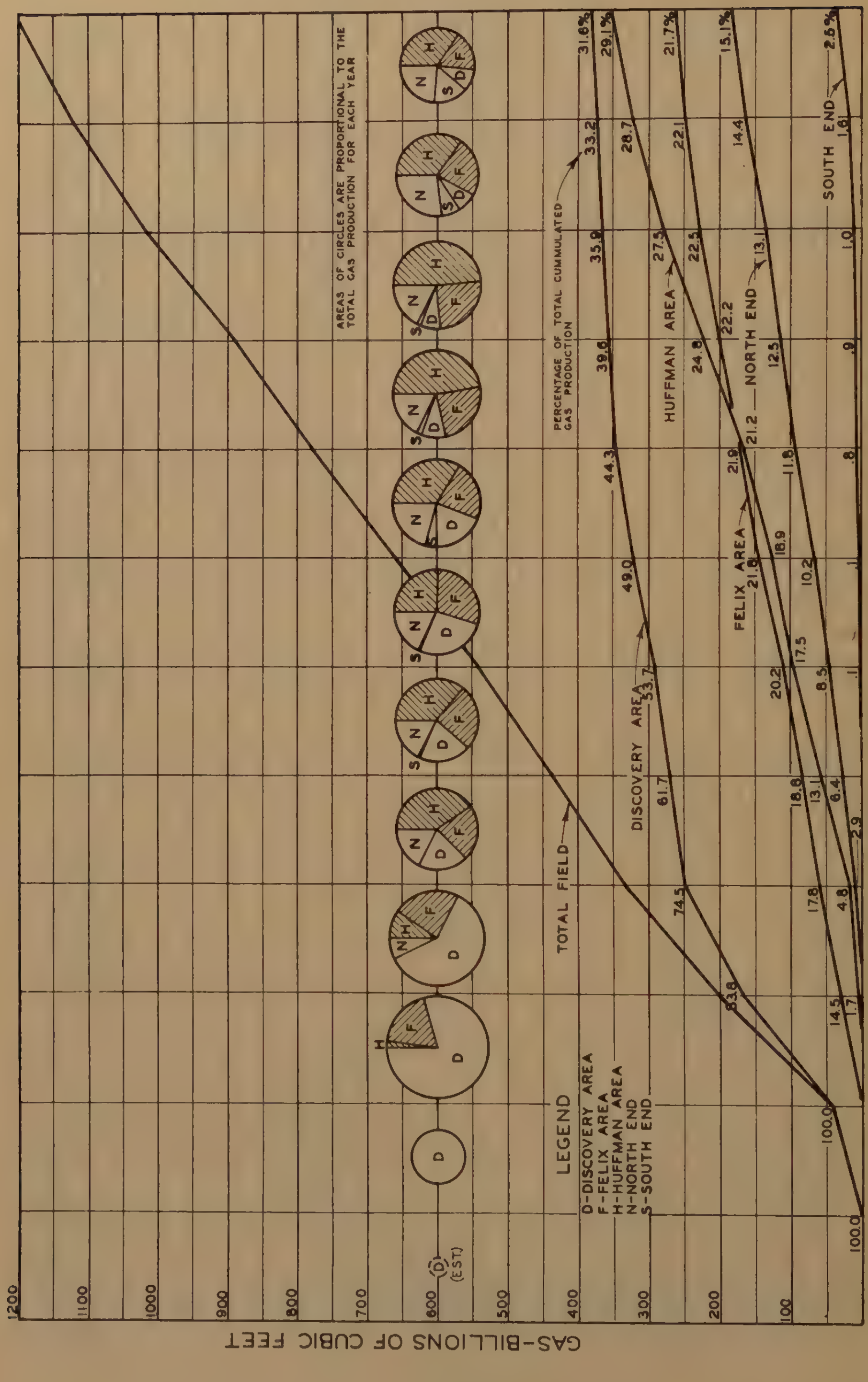

FIG. 11.—CUMULATED GAS PRODUCTION, KETTLEMAN NORTH DOME, TEMBLOR ZONES.

Hills, 65.3 and 50.8 per cent of the oil and gas, respectively, had been removed from the Huffman and Felix areas alone and virtually all of the production came from the northwest half of the field.

The Temblor formation, from which all the production of the field discussed has been removed, is composed of sand and shale bodies varying in thickness from approximately 1250 to 1900 ft. As a matter of convenience in correlation and reference work, the formation has been segregated into five horizons designated as zones I, II, III, IV and V. Zone I is not productive in the northwest end of the field, but each of the other zones has one or more productive sands separated by shales or very fine-grained, tight sands, making it possible to isolate and produce the individual sand members from the rest of the zone or zones. The large number of multiple-zone wells in zones II, III, IV and V in the areas in the northwest end of the field has resulted in a more or less uniform depletion of the zonal pressures in these areas of the four zones mentioned.

Zonal pressure tests in the southeast-end wells, however, indicate that unequal drainage through the individual zones to the northwest end of the field has caused pressure differences as great as 700 lb. per sq. in. between zones in this area (Fig. 9). Permeability tests show that the magnitude of the drainage through the various zones has been in agreement with the permeability values of the individual zones; i.e., zone III, which has the highest permeabilities, has the lowest reservoir pressure, indicating the greatest drainage, and vice versa; zones IV and V, which have the lowest permeabilities, have the highest pressures. These zonal pressure differences have complicated production problems in the southeast end of the field, and particularly the study of pressure maintenance by gas injection, which is under consideration.

Low oil recoveries, in addition to inequitable allocation of production to and within the field, have been caused also by excessive gas production. The depletion of reservoir pressure by excessive gas production and the subsequent effect on oil recoveries has been the basis of numerous studies and reports at Kettleman Hills. As stated previously, more than 1200 billion cubic feet of gas had been produced from the field by the end of 1939. Approximately 40 per cent of this gas came from wells having gas-oil ratios of 10,000 cu. ft. per barrel or higher produced primarily for gas sales purposes. The competitive properties constituting approximately 3.2 per cent of the acreage of the field have produced nearly 19 per cent of the total gas production of the field. The average gas-oil ratio of the field at the end of 1939 was 5490 cu. ft. per barrel.

TABLE 3.—*Approximate Formation Volumes of One Barrel of 36° Gravity Oil and Accompanying Gas at Reservoir Conditions (220°F.)*

Pressure, Lb. per Sq. In.	Gas-oil Ratio, Cu. Ft. per Bbl.		
	1000	2500	5000
3000	1.60[a]	3.20	5.70
2000	2.00	4.45	8.45
1000	3.50	8.50	16.80
500	6.90	17.80	36.00

[a] Example: One barrel of oil and 1000 cu. ft. of gas measured at standard conditions (60°F. and 14.73 lb. per sq. in. absolute) occupy 1.60 bbl. of space at formation conditions.

Table 3 lists the formation volume equivalents for various gas-oil ratios at different reservoir pressures. The data show that a substantial reduction of the gas-oil ratio of the field in the past would have reduced materially the formation volumes produced, and thus would have led to a lower reservoir-pressure decline. Referring to Table 3, a reduction of 50 per cent in a 5000-cu. ft. per barrel gas-oil ratio at 3000 lb. per sq. in. reservoir pressure would have reduced the formation volumes produced 44 per cent,

and an 80 per cent reduction in a 5000-cu. ft. per barrel ratio would have reduced the formation volumes removed 72 per cent.

During 1940 a plan for pressure maintenance by gas conservation was put into effect in the southeast end of the field. Such a plan has never been tried in the northwest end of the field because it has not been possible there to obtain the cooperation of all operators, upon which the success of a plan of this nature depends.

Void volume calculations of the Temblor productive sand bodies and data on oil recoveries from fields having reservoir-pressure maintenance programs indicate that had all the operators at Kettleman Hills agreed originally on a plan of pressure maintenance by gas conservation the ultimate oil recovery from all properties would probably have been increased materially.

Summary

The development and application of subsurface-pressure data have given the production engineer an understanding of reservoir pressure conditions and a method of evaluating the ability of a well to produce which he has not had before. It has enabled him to determine the effect of various production policies on the field, to determine more accurately the potential and potential decline of wells, and to select to better advantage equipment suitable for the production of each well. These and numerous other applications have made subsurface-pressure work a routine part of production engineering.

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DISCUSSION

R. Winterburn,* Los Angeles, Calif.—Mr. McAllister is to be commended for presenting a comprehensive review of the development and use of depth-pressure data in Kettleman Hills, which illustrates the varied ways in which these data may be used in solving practical problems.

Pressure data in the Wilmington field have been obtained since the beginning of development. This information has been successfully applied to problems comparable to those mentioned by Mr. McAllister. Two conditions in the field have made possible studies of a slightly different nature: (1) rates of withdrawal have been steadily reduced under curtailment, which has enabled observation of the effects of such restriction of flow on decline of formation pressures; (2) the field is divided into separate blocks by sealed faults, which has made it possible to study the effect of different well spacing on the individual blocks upon pressure declines and efficiency of utilization of gas energy.

An additional application of depth-pressure data, which could be used to advantage in certain fields, is the use of the pressure decline accompanying withdrawal of known quantities of oil and gas in conjunction with pressure-volume-temperature data in computing the total amount of oil and gas in the reservoir. Such information should be useful as an aid to reserve estimates. After the field is depleted, or nearly depleted, the percentage of the original oil recovered and the amount available for secondary recovery methods may be determined. Numerous other applications of such information undoubtedly will suggest themselves.

Many multiple-zone wells have been drilled in the Wilmington field, in which two or three zones are produced separately from the same well. The zones are separated by cemented blank sections and produced separately through flow strings packed off in these blank sections. In such wells, it is possible to obtain a traverse with a pressure recorder only in the lowest zone. Recently pressure data are being successfully obtained in the upper zones in such wells by the use of fluid-level determinations in conjunction with observed surface pressures.

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The use of a portable compressor to depress the fluid level has increased the accuracy of extrapolations by enabling determination of gradients in the casing and by reducing the length of the extrapolations.

Determinations of potential from depth-pressure data are based on the assumption of a straight-line relation between formation pressure and production rate. In regard to the statement that it was not uncommon for productive indices to vary for different rates of flow I would like to ask Mr. McAllister if these variations in the value of the index follow any consistent pattern and whether they can be attributed to any condition, such as variation in ratio or differential pressure between zones, in the particular wells in which they occur.

E. W. McAllister (author's reply).—The possible variation of productivity indices for different rates of flow is not uncommon in Kettleman, particularly in the southeast end of the field. Because of the zonal pressure differences existing in that end of the field, it is possible to produce multiple-zone wells at low rates of flow, so that the zone or zones of low pressure will not contribute to the production of the well. The production rate may then be increased so that all zones are contributing, resulting in an apparent increase in productivity.

This may be considered a special case. However, in single-zone wells that may tend to be gassy, and particularly if the sand interval open to the well is of low permeability, high rates of flow will cause the release of gas from solution within the formation, thus restricting the flow to the well, resulting in a decrease in productivity.

The California Oil Umpire's office, which for purposes of oil allocation accepts well potentials calculated from subsurface data, applies a discount formula to the theoretical well potentials in order to take care of any decrease in productivity. This, of course, penalizes a well of constant or increasing productivity with increasing flow rate.

E. K. Parks,* Los Angeles, Calif.—This paper is commended as a historical document. Engineers, like physicians, should have an ample supply of "case histories," for there is nothing like the reaction of a patient to prove or disprove a treatment. McAllister gives practical applications of much that has appeared in technological papers, and offers plausible explanation of variation of behavior. His correlation of depth-pressure surveys with reservoir performance is especially valuable, because there is such paucity of these analyses. One reason is that analysis itself is a laborious process, and few are privileged to have the required time. Another is that this type of information is usually considered confidential. We have to thank the author and his company, the Kettleman North Dome Association, for a valuable contribution. The author might well have noted that the pioneer of the depth-pressure recorder in California was Mr. E. G. Gaylord, of The Standard Oil Company of California.

The discussion of allocation principles is timely, for equity in proration and in unit planning is still a prime difficulty. Views backed by facts are especially helpful.

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Slim-hole Drilling on the Gulf Coast

By I. W. Alcorn,* Member A.I.M.E.

(Los Angeles Meeting, October 1940)

The cost of drilling in the past few years of proration and ever decreasing allowables has received increasing thought and study. It seems to parallel the strides made with respect to pumping problems in 1932 and 1933. Low profit margins stimulate the search for economies.

Any discussion of slim-hole drilling involves a multitude of abstract values, and the problem can be attacked only by a study of records and rational thinking. In a measure, traditional methods must be studied with a questioning attitude.

The words "slim hole" may be somewhat misleading, as the term is entirely relative. For that reason I wish to define it as used in this discussion. On the Gulf Coast, I would define a normal hole as one in which 10¾-in. surface casing has been set and below which a 9⅞-in. hole is dug. With this as a datum, holes of larger diameter below surface would be called "large holes," with 12¼ in. as the "extra large" class and holes of smaller diameter classed in the slim-hole range, 6¼ in. representing about the minimum size. The optimum size has not been definitely determined, but the preference is for a program that would call for setting 8⅝-in. surface casing and digging a 7¾-in. hole. Different sections of the country might very properly deviate from this practice because of differences in depth, formations, regulations, or other factors.

This paper will be confined to a discussion of the drilling of exploratory wells, as the drilling of this class of wells is quite a different problem from that of drilling a proven field, although many of the same considerations apply in both cases, as will be apparent.

Although for many years shallow slim-hole and core-test holes of small diameter had been dug, it was not, I believe, until the fall of 1937 that serious consideration was given to its application in drilling wells 7000 ft., 8000 ft. and 9000 ft. deep on the Gulf Coast. This does not mean that nearly all such wells drilled on the Gulf Coast now are of the slim-hole variety, but only that efforts have been aimed in that direction with very encouraging results and there has been a very definite trend to reduce the size of holes, a trend that probably will continue.

As to exploration policy, there appear to be two distinct and opposite views. The one usually followed in the past was more or less designed to "shoot the works" on one well. Generally on the Gulf Coast, the depth at which production might be obtained is limited by the drilling equipment and economics. With this thought in mind, wildcat wells are often planned with the idea of carrying the depth to 10,000 ft., or even 15,000 ft. All of the possible hazards are anticipated and the general drilling and casing programs are so predicated. Such wells contemplate the drilling of large-diameter holes; the setting of at least one protective string of casing and an extensive coring policy, all of which finally adds up to an expensive well.

As opposed to this general policy is the slim hole. This, on the Gulf Coast, recognizes that new discoveries represent gam-

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bling odds of about 7 to 1 against the discovery of commercial production. It also takes the position that 10,500 ft. represents the lower limit of economical production and that below that point the odds are greatly increased of even finding oil production. Production found below that depth on the Gulf Coast would probably be of the distillate variety and, if so, would certainly be an uneconomic venture. Therefore, the rig chosen would be one capable of drilling only to that depth, or even less.

THE PURE OIL COMPANY

DAILY ROTARY DRILLING REPORT

DIVISION__________ DISTRICT__________ LEASE__________

CONTRACTOR__________ RIG NO.__________ WELL NO.__________

FORMATION RECORD

FROM	TO	FORMATION	COLOR OR SHOWING	FEET DRILLED	FEET REAMED OR REMARKS

CORING RECORD

FROM	TO	RECOVERED	FORMATION	SHOWING	SIZE & MAKE BARREL

BIT RECORD

BIT NO	SIZE	MAKE & TYPE	MAN'F'R'S SERIAL NO	DEPTH		HOURS BIT RUN TO				CONDITION
				IN	OUT	DRILL	REAM	CORE	TOTAL	

BIT ODOMETER RECORD

BIT NO	READING		TOTAL REVOLUTIONS
	IN	OUT	

SURVEY RECORD

DEPTH	NO DEGREES	INSTRUMENT

OPERATION	HOURS
BLOCKS, RESTRING	
BLOWOUT PREVENTER	
CASING RUN AND CEMENT	
COMPLETING	
CORING (ACTUAL)	
DRILLING (ACTUAL)	
DRILLPIPE, CHANGE OR REPAIR	
DRILLPIPE LAYING DOWN	
DRILL STEM TESTING	
FISHING *	
MUD CIRCULATING *	
NEW EQUIPMENT INSTALLED *	
PERFORATING	
PUMP REPAIRS	
REAMING (ACTUAL)	
RIGGING UP	
RIG REPAIRS	
ROUND TRIP TO CHANGE BIT	
SURVEY DEVIATION	
SURVEY, ELECTRIC LOG	
WAITING, CEMENT TO SET	
WAITING, FUEL AND WATER	
WAITING, ORDERS	
WAITING, TOOLS	
WAITING, WEATHER	
*	

PUMP AND DRILLING DATA

PUMP USED	NO. 1	NO. 2
HOURS RUN		
LINER SIZE		
PUMP R P M		
PUMP PRESSURE		
AVERAGE STEAM PRESSURE		
TEMP BOILER FEED WATER		
ROTARY R.P.M.		
WEIGHT OF D.P. FREE (Pts. or Lbs.)		
WT. OF D.P. WHILE DRLG. (Pts. or Lbs.)		
WEIGHT ON BITS (Pts. or Lbs.)		
NUMBER AND SIZE LINES		
SIZE AND WT. OF DRILL PIPE		
ODOMETER READING—BEG. OF TOUR		
ODOMETER READING—END OF TOUR		
NUMBER OF ROUND TRIPS		

MUD REPORT

MUD	BEGINNING OF TOUR	MIDDLE OF TOUR	END OF TOUR
WEIGHT PER GAL.			
FUNNEL VIS 1500 IN—1000 OUT			
PERCENT SAND			
PERCENT SOLIDS			
TEMPERATURE			
GEL. IN GRAMS			
FILTER CAKE			
FILTRATE			
PH. VALUE			

MUD CONDITIONING MATERIALS

KIND OF MATERIAL	QUANTITY

DRILL PIPE TALLY

KELLY ABOVE ROTARY—BEG. TOUR	
PIPE PUT IN HOLE	
TOTAL	
LESS- KELLY ABOVE ROTARY END TOUR	
TOTAL	
LESS -PIPE LAID DOWN	
TOTAL HOLE MADE	
DEPTH BEG. OF TOUR	
DEPTH -END OF TOUR	

PIPE IN HOLE END OF TOUR

FOURBLES	THRIBBLES	DOUBLES	SINGLES

DRILL COLLARS

NO	SIZE O. D.	SIZE I. D.	LENGTH

REMARKS: *(EXPLAIN BELOW IN DETAIL)

Tour Ending______ A. M. / P. M. Date__________, 194__ APPROVED

Signed__________ DRILLER __________ SUPERINTENDENT

NOTE: Under "Remarks" show material needed; give reasons for repairs; report anything of interest on condition of hole or rig.

FIG. 1.—DAILY ROTARY DRILLING REPORT.

The major costs of wildcat drilling are: drilling, including rig time and labor, casing, fuel, mud, coring, bits and reaming in the order mentioned; also included might aptly be the cost of moving in and providing a marine structure on which to set the rig. If we acknowledge this, we find that we can employ a much smaller and compact Diesel or gas-engine mechanical rig satisfactorily, which reduces greatly the cost of foundations, moving in and fuel. The reduction in hole size materially reduces the bit cost, drilling cost, reaming cost, casing cost

and mud costs. The policy of this kind of operation also reduces coring to a minimum, if it does not entirely eliminate it, so that in the over-all picture the cost of drilling exploratory slim holes is approximately one-half to one-fourth that of drilling the large holes, which means that two to four wells can be drilled for the price of one, thereby decreasing the gambling odds per dollar.

It might be well to investigate in more detail the basis upon which these general statements and premises were determined.

To begin with, it is necessary to compile an accurate and detailed report of records from which many of the conclusions are drawn. The first step in this direction is to secure the necessary information from the field, or, in other words, from the drilling report. As our drilling reports were incomplete in this respect, a new one was adopted incorporating the desired information, copy of which is indicated in Fig. 1. Supplementing this report are two other reports, one covering cementing jobs and the other drill-stem testing, electrical logging and gun perforating. From this information, a time-depth drilling curve is constructed, as shown in Figs. 2 to 5. This information is then transferred to two summary sheets, one being a summary showing the complete breakdown of time in hours together with

BIT RECORD

				DRILLING				CORING				RMNG.		TOTALS				
No.	Make	Type	Size	From	To	Hrs.	Feet	From	To	Hrs.	Feet	Hrs.	Feet	Hours	Feet	Cond.	Cost	Cost/Ft.
1	POCO	2w	17¼"	0	163	3	163							3	163	Sharp		
2	Reed	"	12¼"	163	941	13½	778							13½	778	Fair	33.68	.043
3	"	"	"	941	1269	8¾	328					8	778	8¾	328	Broke Pin off B.C.	33.68	.102
4	"	"	"	1269	1435	3½	166							3½	166	Good	33.68	.202
5	"	"	8¾"	1435	3407	37½	1972							37½	1972	Dull	24.06	.012
6	"	"	"	3407	4600	31½	1193							31½	1193	"	24.06	.022
7	"	"	"	4600	4725	8¼	125					3	306	8¼	125	"	24.06	.193
8	Hughes	TriCone RB	"	4725	5008	19¼	283							19¼	283	"	96.00	.339
9	"	"	"	5008	5145	13¾	137							13¾	137	"	96.00	.700
10	Reed	2w	"	5145	5353	12¾	208							12¾	208	"	24.06	.115
11	Hughes	TriCone RB	"	5353	5726	23¼	373							23¼	373	"	96.00	.257
12	Reed	2w	"	5726	6032	19	306							19	306	"	24.06	.078
13	"	"	"	6032	6520	26½	488							26½	488	"	24.06	.049
14	"	"	"	6520	6729	9¾	209							9¾	209	"	24.06	.115
15	"	"	"	6729	6833	14¾	104							14¾	104	"	24.06	.231
16	"	"	"	6833	7131	27½	298							27½	298	"	24.06	.081
17	"	"	"	7131	7144	4½	13							4½	13	"	24.06	1.85
18	Hughes	TriCone RB	"	7144	7182	8¾	38							8¾	38	"	96.00	2.52
19	Reed	2w	"	7182	7308	15¾	126							15¾	126	"	24.06	.191
20	"	"	"	7308	7553	21	245							21	245	"	24.06	.098
21	"	"	"	7553	7856	30¾	303							30¾	303	"	24.06	.079
21RR	"	"	"					Circulating @6665										
22	Hughes	TriCone RB	4¾"	Drlg. Cmnt.		6349-	6373-	3Hrs.								Sharp		
						353¼	7856					11	1084	353¼	7856		797.82	.1015

MUD COSTS

100# Sod. Tetra Phos. @16¢#	$16.00
25# Bicarbonate of Soda @$2.85/100#	.71
600# Buromin @$17.75/100#	106.50
84 Sx. Aquagel @$47.69 Ton	200.30
1 Bale Fibrotex @$3.14 Bale	3.14
35x. Mica @$80.70 Ton	12.10
	$338.75

MAN HOURS

Moving Material	322
Rigging Up	693
Piling	142
Erecting Derrick	373
	1530

FIG. 2.—DATA FOR PLOTTING FIG. 5.

other pertinent data for all wells drilled, and the other covering the cost analysis, and both showing the total for all wells and the percentage of the total.

BREAKDOWN OF OPERATIONS TIME

	Hours	% Hours
Drilling	353¼	41.96
Coring	0	0
Reaming	11	1.31
Rng.-Cmnt.-Csng.	23	2.73
W.O.C.	131½	15.62
Fishing	5¾	.68
Syfo	11½	1.36
Schlumberger	18¼	2.17
Rep. Rig	18¼	2.17
Mix Mud	4¼	.50
Circulating	12	1.43
Ro. Trip-Chg. Bits	99	11.77
Miscellaneous	14½	1.72
W.O. Weather	1½	.18
W.O. Material	6¼	.74
Perforating	12	1.42
Working on Brkn. Csng.	18	2.15
String. Block	11½	1.36
Laying down D.P.	14¼	1.69
Comp.-Watching & Gauging Well	76	9.04
	841¾	100.00

SYFO RECORD

Depth	Deviation
500'	0°
1000'	1°
1400'	0°
1900'	0°
2400'	0°
2900'	1°
3400'	1°
3900'	0°
4400'	0°
4900'	1°
5400'	1°
5900'	1°
6700'	3½°
7000'	3½
7440'	2°

DRILLERS RECORD

	Hours	Feet	Feet/Hr.
Toney	101¼	2538	25.06
Kebodeaux	80¼	1839	22.91
Broussard	81¾	2136	26.12
Hackett	90	1343	14.92
	353¼	7856	22.23

FIG. 3.—DATA FOR PLOTTING FIG. 5.

Tables 1 and 2 show a grouping of wells to similar depths and other similar characteristics, but of different sizes of holes; A, B, C, D being 12½ in., 9⅞ in., 8¾ in. and 7¾ in., respectively. Table 1 was taken from the summary of hours and Table 2 from the cost summary. Table 3 is a grouping of these same wells showing the percentage of totals for each group.

Table 4 is a final grouping and classification summary of these wells covering both costs and pertinent data. It is from this tabulation that the clearest comparisons can be seen. The wells are all about the same depth but the "total days" varies from average of 97⅓ to 35⅔; total cubic feet, from 9921 to 3640; bit changes, from 78 to 21; footage per bit, from 128 to 395; actual cubic feet per hour, from 11.3 to 11.14; actual feet per hour, from 9.56 to 23.97; bit cost per foot, from 0.524 to 0.071; coring cost per foot, from 0.562 to 0; reaming cost per foot, from 0.24 to 0.054; drilling (including time and bits) per foot, from 3.25 to 0.95; fuel cost per foot, from 1.55 to 0.062; mud cost per foot, from 0.269 to 0.033; casing cost per foot, from 3.96 to 0.697 and total cost per foot, from 9.81 to 1.79.

The interesting points regarding this tabulation appear to be, aside from the progressive reduction in values as the size of hole is decreased, in the actual cubic feet per hour excavated, casing costs and fuel costs. The actual cubic feet per hour remains about the same regardless of the hole size. This is quite significant, especially when translated into lineal feet, as noted in the column showing actual footage per hour and the "bit costs." The casing costs are significant in that protective strings were run only in the large holes, and that

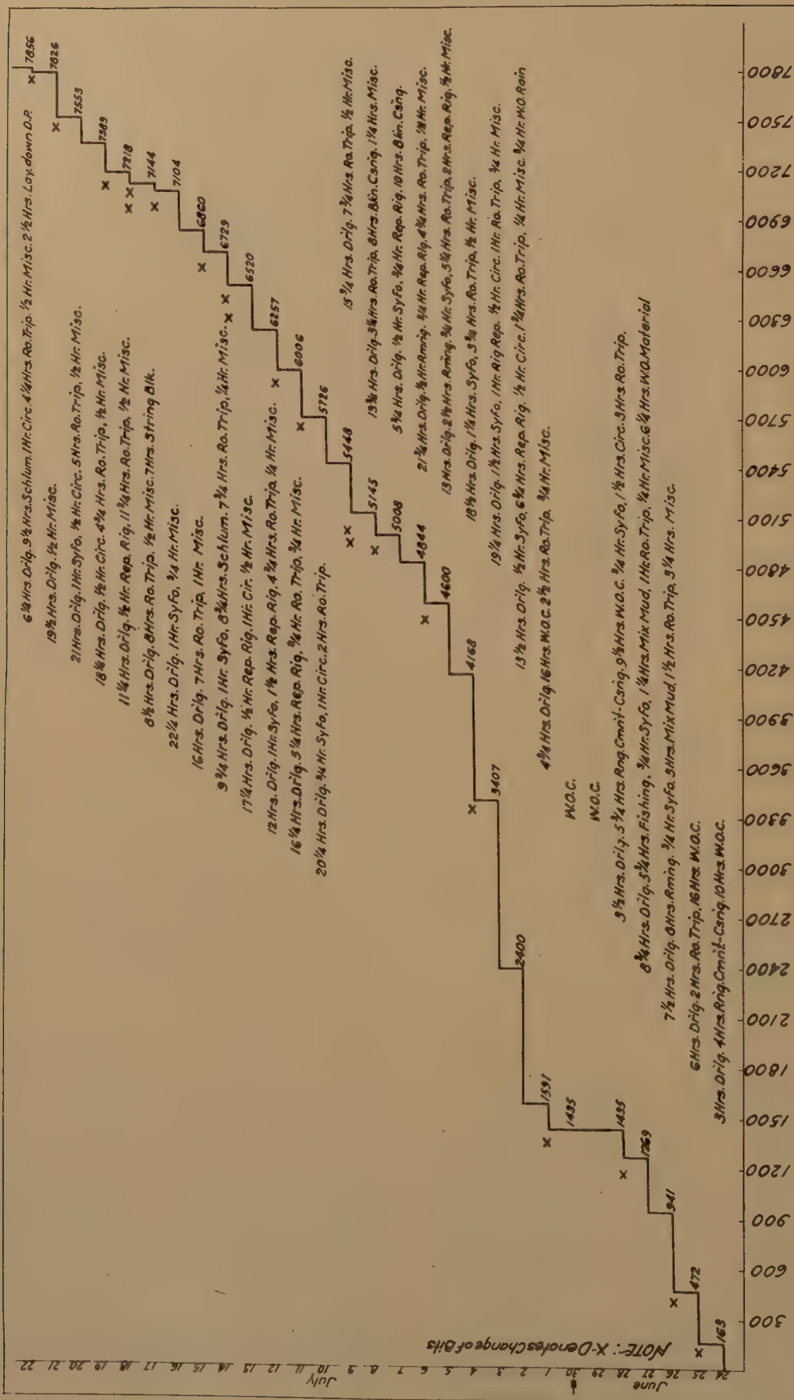

FIG. 4.—DATA FOR PLOTTING FIG. 5.

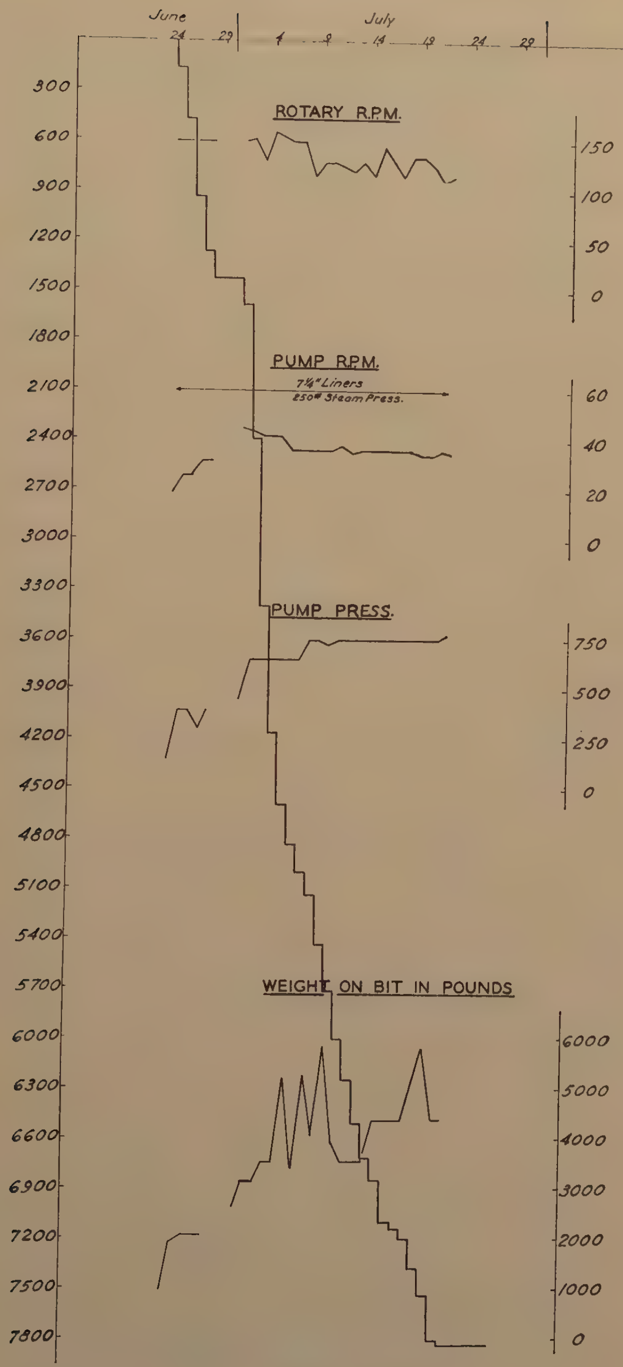

FIG. 5.—DRILLING CURVE.

TABLE 1.—*Drilling Well Analysis*

HOURS

Operation	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	D-1	D-2	D-3	Total Hours	Percentage of Total
Rigging up after spudding	325.00	23.00	38.00	46.00	33.25	0	7.00	18.00	0	0	14.25	504.50	3.05
Drilling	970.75	859.25	787.25	906.25	481.25	349.50	365.00	570.75	415.75	289.25	330.75	6,325.75	38.05
Reaming	274.75	28.75	35.50	119.00	11.00	5.50	51.75	34.25	58.75	12.50	9.00	640.75	3.85
Coring	80.75	14.75	90.75	27.75	8.50	21.75	0	49.25	0	0	0	293.50	1.76
Fish, bit plug and core barrel	155.75	0	64.25	89.50	0	0	0	0	0	0	0	309.50	1.86
Installing new equipment	20.00	0	0	29.50	0	0	0	0	0	0	0	49.50	0.29
Repair rig	261.75	60.25	40.50	85.50	26.00	83.00	28.50	84.50	39.75	21.25	44.75	775.75	4.66
Round trip and changing bit	613.75	277.75	198.50	366.00	182.00	170.75	42.50	257.25	101.75	75.75	69.50	2,455.50	14.77
Fishing	63.50	0	68.25	0	0	0	52.00	64.00	0	0	24.00	271.75	1.66
Setting casing	133.00[a]	31.25	51.00	17.50	21.00	35.50	35.50	32.75	16.00	26.00	19.00	418.50	2.52
Waiting on cement	375.00	122.00	254.00	120.00	83.00	168.50	208.00	88.25	116.50	99.50	100.50	1,735.25	10.43
Deviation surveys	20.25	17.50	19.00	15.50	14.00	21.50	10.00	15.00	8.00	4.50	8.00	153.25	0.92
Mix mud	122.50	2.25	0	4.25	5.25	16.25	0	11.00	9.00	0	0	170.50	1.05
Circulate mud	68.25	11.75	27.75	28.25	46.00	24.00	25.25	72.25	15.25	14.00	9.50	342.25	2.06
Change and repair drill pipe	82.50	8.50	24.00	17.50	0	9.50	0.50	0	8.50	0	7.00	158.00	0.95
Electrical logging	13.00	10.00	15.00	4.75	8.50	14.25	24.25	28.50	13.75	5.00	13.00	150.00	0.90
Waiting on tools	122.00	0	8.00	0	0	0	17.25	3.50	0	3.50	14.50	168.75	1.01
Waiting on orders	0	0	0	0	0	3.00	0	0	1.00	21.00	20.00	45.00	0.27
Waiting on weather	15.25	0.25	0	4.50	0	0	0	8.00	1.25	0	0	29.25	0.17
Waiting on fuel or water	0	3.50	0	0	93.00	6.25	0	0	0	0	0	102.75	0.62
Repair pumps	7.50	15.25	1.00	14.75	16.00	4.25	61.50	32.75	23.75	44.00	28.75	249.50	1.50
Restring blocks	36.25	9.75	14.00	20.00	7.75	0	7.25	5.00	4.00	25.50	2.75	132.25	0.80
Miscellaneous	61.00	99.75	20.25	65.00	28.75	25.75	53.00	45.00	53.00	43.25	40.75	535.50	3.22
Perforate and D.S.T.	0[b]	0[b]	0[b]	0[b]	0	0	19.50	0	0	0	0	19.50	0.12
Lay down drill pipe and abandon	0[b]	0[b]	0[b]	0[b]	46.50	0	0	28.00	25.75	59.00	132.00	291.25	1.75
Completion	0[b]	0[b]	0[b]	0[b]	0	152.00	144.00	0	0	0	0	296.00	1.78
Totals	3,822.50	1,595.50	1,757.00	1,981.50	1,111.75	1,111.25	1,252.75	1,448.00	911.75	744.00	888.00	16,624.00	100.00

[a] Including casing to 7700 ft. (9⅝ in.). [b] Data do not go to total depth.

TABLE 1.—(*Continued*)
MISCELLANEOUS DATA

Operation	A-1	A-2	A-3	B-1	B-2	B-3	C-1	C-2	D-1	D-2	D-3	Total Hours	Percentage of Total
Date completed or abandoned					11/2/39	9/23/38	1/31/39	7/4/40	7/16/38	9/23/38	12/4/38		
Number days spud in to completion or abandon	150.00	66.00	75.00	82.00	46.33	46.33	52.56	60.33	39.00	31.00	37.00	685.55	
Total feet drilled	8,987	7,710	8,282	8,472	8,400	8,197	7,451	8,957	8,293	7,989	8,051	90,789.00	
Feet drilled per day (total time)	59.9	116.7	114.30	103.4	182.61	176.90	141.50	148.50	212.00	257.70	217.50	132.00	
Actual feet drilled per hour	9.26	8.97	10.53	9.34	17.45	23.45	20.42	25.40	20.00	27.62	24.30	14.30	
Cubic feet formation cut	12,480.00	8,634.50	8,647.00	6,232.50	5,496.80	5,698.00	4,313.00	4,394.50	3,708.00	3,592.00	3,619.00	66,815.30	
Cubic feet per day	83.20	131.00	115.30	76.10	118.65	122.90	81.95	72.80	95.00	115.90	97.80	97.40	
Cubic feet per hour	12.84	10.05	11.00	6.88	11.42	16.30	11.82	12.40	8.91	12.42	10.90	10.60	
Bit change incl. core bits	123.00	70.00	41.00	78.00	34.00	34.00	35.00	41.00	26.00	18.00	19.00	519.00	
Number wire-line cores	181.00	0	69.00	76.00	0	0	0	0	0	0	0	326.00	
Number conventional cores	10.00	4.00	1.00	0	7.00	9.00	0	13.00	0	0	0	44.00	
Average footage per bit	73.00	112.00	202.00	116.00	276.47	241.10	212.90	193.40	318.96	443.83	423.50	175.00	
Wire-line core bit:													
Number feet cut	449.00	0	484.00	156.00	0	0	0	0	0	0	0	1,089.00	
Number feet recovered	326′1″	0	424′0″	115′7″	0	0	0	0	0	0	0	865′8″	
Percentage of recovery	72.60	0	87.50	73.80	0	0	0	0	0	0	0	79.40	
Conventional core bit:													
Number feet cut	63.00	77.00	18.00	0	115.00	168.00	0	218.00	0	0	0	659.00	
Number feet recovered	49′0″	71′0″	0′6″	0	93′6″	133′0″	0	181′0″	0	0	0	528′0″	
Percentage of recovery	78.10	92.20	0.28	0	81.30	79.30	0	88.00	0	0	0	80.20	
Man-hours:													
Rigging up and moving material to spud	2,930.00	3,737.00	3,053.00	2,570.00	3,834.00	2,192.00	2,142.00	1,273.00	1,865.00	1,609.00	2,045.00	27,250.00	
Erecting derrick structure	991.00	606.00	1,736.00	986.00	898.00	0	288.00	251.00	1,038.00	488.00	688.00	6,388.97	
Piling	1,831.00[c]	0	0	2,470.00	61.00	0	906.00	0	0	0	0	5,268.00	
Total to spudding	5,752.00	4,343.00	4,789.00	6,026.00	4,793.00	2,192.00	3,336.00	1,524.00	2,903.00	2,097.00	2,733.00	40,488.00	

Large Holes
A-1—Casing: 18⅝″ surface @ 1400′
13⅜″ at 4600′; 9⅝″ at 7700′
A-2—Casing: 13⅜″ surface @ 2421′; 9⅝″ @ 7710′
A-3—Casing: 13⅜″ surface @ 2075′; 9⅝″ @ 7617′

[c] Does not include piling contract.

Normal Holes
B-1—Casing: 10¾″ surface @ 2100′
B-2—Casing: 10¾″ surface @ 1163′
B-3—Casing: 10¾″ surface @ 1720′

Semislim Holes
C-1—Casing: 9⅝″ surface @ 1390′
C-2—Casing: 9⅝″ surface @ 1173′

Slim Holes
D-1—Casing: 8⅝″ surface @ 2006′
D-2—Casing: 8⅝″ surface @ 1950′
D-3—Casing: 8⅝″ surface @ 2015′

accounts for the high costs in this group. It seems to be safe to assume that the protective strings were not necessary to the drilling of the wells.

The fuel costs reflect advantages to be obtained both by reason of decrease in drilling time and in the use of the slim-hole Diesel mechanical rig in effecting fuel economies.

A summation of the entire theory of hole-size reduction might be graphically illustrated as in Figs. 6 and 7, Fig. 6 being based on the relationship between cubic feet per foot of hole and time in minutes per foot of hole as affecting total time and actual time.

The information is taken from the tabulated data, using the average figures and representing depth of 8111 to 8356 ft. The total time represents the time from spudding to total depth and actual time only the time rotating cutting hole. The slope of these two curves is significant and also their tendency to converge in the smaller hole range. The space between the curves, of course, represents ineffective work and shows a progressively greater percentage of ineffective time as the hole size is increased. This is because the smaller footage per bit required more round trips, more reaming time, and other work. Fig. 7 is the same information using the diameter of hole in

TABLE 2.—*Cost of*

Operation	A-1	A-2	A-3	B-1	B-2
Total cost all bits	$7,039.28	$5,153.95	$1,655.06	$3,199.00	$969.65
Total bit cost per foot	0.794	0.668	0.198	0.378	0.115
Coring:					
Bits	737.20	684.00	309.73	228.00	162.00
Coring time	1,293.00	246.00	1,570.00	464.00	142.00
Fish, bit plug and pulling bit	2,480.00	0	1,075.00	1,490.00	0
Rotating time with regular coring bit	1,000.00	400.00	100.00	0	700.00
W/L cores @ $17.50 each	3,167.50	0	1,207.50	1,330.00	0
Reed rental @ $5.00 per day	275.00	0	250.00	520.00	0
Total coring	8,952.70	1,330.00	4,512.23	4,032.00	1,004.00
Reaming:					
Full-hole reaming time	3,980.00	413.00	587.00	1,985.00	183.00
Rat-hole reaming time	200.00	66.60	0	0	0
Underreaming time	392.00	0	0	0	0
Total reaming	4,572.00	479.60	587.00	1,985.00	183.00
Drilling:					
Time on bottom make hole	16,200.00	4,469.95	13,130.00	9,470.00	8,030.00
Round-trip time	10,100.00	4,230.00	3,290.00	6,100.00	2,335.00
Drilling-pit cost	6,661.08	4,469.95	1,345.33	2,971.00	807.65
Total drilling	32,961.08	13,169.90	17,765.33	18,541.00	11,172.65
Fuel:					
Oil, price per bbl	1.35		1.60	1.35	0
Oil, total cost	14,700.00		14,591.00	9,950.00	0
Barge rental rate	400.00[a]		0	400.00[a]	0
Barge total rental	2,000.00		0	955.00	0
Towing cost	258.00		0	58.00	0
Gas, cost per M cu. ft		0.15	0	0	Royalty
Gas, total cost		7,920.00	0	0	88.40
Total fuel	16,958.00	7,920.00	14,591.00	10,963.00	88.40
Mud:					
Material	3,527.00	458.00	798.00	308.26	462.90
Mix mud	2,080.00	230.00	0	217.00	87.50
Total mud	5,607.00	688.00	798.00	525.26	550.40
Casing:					
Material	44,378.00	17,403.00	26,546.00	5,505.00	2,276.96
Running and cementing	2,180.00	520.00	850.00	292.00	350.00
Waiting on cement	6,230.00	2,300.00	4,230.00	2,010.00	1,380.00
Total casing	52,788.00	20,223.00	31,626.40	7,807.00	4,006.96
Grand totals	121,838.78	43,810.50	69,879.96	43,853.26	17,005.41

A-1, A-2, A-3, large holes, 12¼". B-1, B-2, B-3, normal holes, 9⅞".

[a] Per month.

inches on the horizontal scale. While individual wells may vary somewhat, it is evident that the data indicate a very definite trend and the average points conform accurately to the charts.

Drilling Operations

B-3	C-1	C-2	D-1	D-2	D-3	Total	Percentage of Total
$1,450.50	$1,165.05	$1,046.78	$714.90	$448.19	$448.19	$23,290.35	5.73
0.177	0.156	0.116	0.086	0.056	0.056	0.257	
462.00	0	300.00	0	0	0	2,882.93	
362.00	0	472.50	0	0	0	4,549.50	
0	0	0	0	0	0	5,045.00	
1,050.00	0	1,410.00	0	0	0	4,660.00	
0	0	0	0	0	0	5,705.00	
0	0	0	0	0	0	1,045.00	
1,874.00	0	2,182.50	0	0	0	23,887.43	5.94
50.00	863.00	450.00	980.00	208.00	152.00	9,851.00	
42.00	0	125.00	0	0	0	433.60	
0	0	0	0	0	0	392.00	
92.00	863.00	575.00	980.00	208.00	152.00	10,676.60	2.66
5,825.00	6,085.00	9,530.00	6,925.00	4,830.00	5,520.00	90,014.95	
1,795.00	2,378.00	2,875.00	1,695.00	1,264.00	1,158.00	37,220.00	
988.30	1,165.05	746.78	714.90	448.19	448.19	20,766.42	
8,608.30	9,628.05	13,151.78	9,334.90	6,542.19	7,126.19	148,001.37	36.47
0	1.62	0.06/gal.	1.75	1.75	1.75		
0	433.68	1,206.96	466.92	283.50	389.28	42,031.34	
0	5.00[b]	0	5.00[b]	5.00[b]	5.00[b]		
0	30.00	0	30.00	20.00	30.00	3,065.00	
0	100.00	0	120.00	80.00	100.00	716.00	
45.00[b]	0	0	0	0	0		
2,160.00	0	0	0	0	0	10,168.40	
2,160.00	573.68	1,206.96	616.92	383.50	519.28	55,980.74	13.54
5,333.50	307.34	3,927.50	485.50	123.32	60.31	15,791.63	
272.00	0	183.00	150.00	0	0	3,219.50	
5,605.50	307.34	4,110.50	635.50	123.32	60.31	19,011.13	4.68
3,064.60	3,369.60	2,395.83	3,396.93	3,331.31	3,897.68	115,565.31	
234.00	234.00	547.00	267.00	433.00	317.00	6,224.00	
1,715.00	2,365.00	1,470.00	1,946.00	1,655.00	1,675.00	26,976.00	
5,013.60	5,968.60	4,412.83	5,609.93	5,419.31	5,889.68	148,765.31	36.67
23,353.40	17,340.67	25,639.57	17,177.25	12,676.32	13,747.46	406,322.58	

C-1 and C-2, semislim holes, 8¾″. D-1, D-2, D-3, slim holes, 7¾″.
[b] Per day.

tion of 30 per cent. Electrical logging and mud-stream analysis have contributed to lessening the amount of coring necessary. Side-wall sampling and, more recently, side-wall coring are also tending to minimize coring.

From a mechanical standpoint, there have been new developments in technique and equipment in recent years that have been very instrumental in following this trend. Among these is the development of internal flush drill pipe, which creates a better balance between friction inside the pipe and velocity in the annular space. For this work we are now using a string of 3½-in. IF made of N-80 steel, permitting equivalent strength with a weight reduction of 30 per cent. Electrical logging and mud-stream analysis have contributed to lessening the amount of coring necessary. Side-wall sampling and, more recently, side-wall coring are also tending to minimize coring. Gun perforating has brought about changes in completion programs, tending to material reductions in rig time and over-all costs. Much improved cementing technique has lessened the hazards of water and gas encroachment, changing what used to be poor practice to good practice and thereby reducing costs. These improvements involve use of wall scratchers, rotation of casing with eccentric couplings, cement retainers and general improvement

in mud control, cement, and other factors. Constant improvement has been made in multispeed drawworks as applied to Diesel or internal-combustion mechanical rigs. gines, compounded and driving both a regular 27½-in. oil-bath rotary table through an eight-speed drawworks and the power slush pump, which is a 7¼ by 14 or 7¼ by 15.

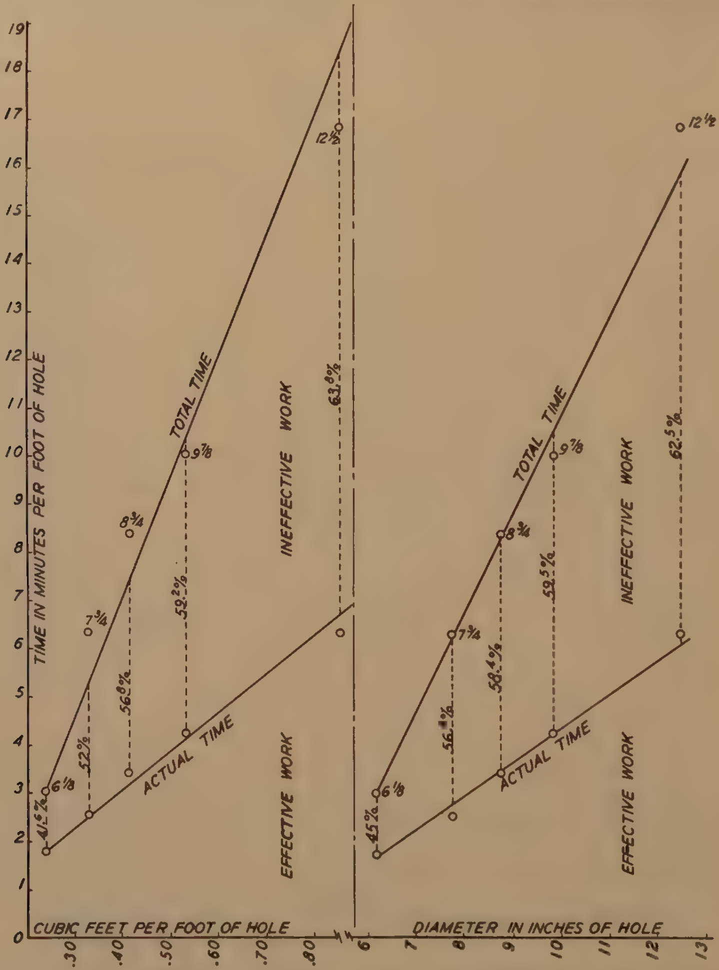

Fig. 6. Fig. 7.

Fig. 6.—Relationship of drilling speed to cubic feet per foot of hole.
Fig. 7.—Relationship of drilling speed to hole diameter.

There is a rather definite trend toward the use of torque converters and hydraulic couplings, which would further increase the desirability of the straight mechanical rig. The rig most familiar on the upper Gulf Coast area is designed for drilling to 9000 ft. with 3½-in. drill pipe. In general, such a rig would be powered with two 220-hp. engines, compounded and driving both a regular 27½-in. oil-bath rotary table through an eight-speed drawworks and the power slush pump, which is a 7¼ by 14 or 7¼ by 15.

A conventional 136-ft. derrick with a 26-ft. base is usually used. A compact utility unit is required, powered by an 85-hp. engine driving through a line shaft the various units such as generator, compressor, wash-down pump and a 6 by 12 power pump for jetting mud. The last-named pump may also serve as a standby for the regular

pump. The entire unit is mounted on 10-in. pipe skids in which compressed air is stored. Rectangular steel mud tanks and fuel tank are also skid mounted.

manufacturers' standpoint, it appears that about 8⅝ or 8¾ in. represents the minimum size in rock bits before structural strength becomes a factor, so in view of the

TABLE 3.—*Percentage of Totals*

Operation, Hours	Percentage of Totals			
	A Wells	B Wells	C Wells	D Wells
Rigging up after spudding	5.38	1.88	0.93	0.56
Drilling	36.44	41.28	34.66	40.80
Reaming	4.72	3.22	3.19	3.13
Coring	2.59	1.38	1.84	0
Fish, bit plug and core barrel	3.07	2.12	0	0
Installing new equipment	0.28	0.70	0	0
Repairing rig	5.06	4.62	4.18	4.16
Round trip and changing bit	15.18	17.08	14.81	9.72
Fishing	1.87	0	4.30	0.94
Setting casing	3.00	1.76	2.53	2.31
Waiting on cement	10.45	8.83	10.97	12.44
Deviation surveys	0.79	1.21	0.92	0.81
Mixing mud	1.77	0.61	0.41	0.35
Circulating mud	1.50	2.33	3.61	1.52
Changing and repairing drill pipe	1.60	0.64	0.02	0.59
Electrical logging	0.53	0.65	1.95	1.25
Waiting on tools	1.81	0	0.77	0.71
Waiting on orders	0	0.07	0	1.65
Waiting on weather	0.21	0.11	0.29	0.05
Waiting on fuel or water	0.05	2.36	0	0
Repairing pumps	0.33	0.83	3.49	3.79
Restringing blocks	0.84	0.66	0.45	1.27
Miscellaneous	2.52	2.84	3.63	5.38
Perforating and D.S.T.	0	0	0.72	0
Laying down drill pipe and abandoning	0	1.11	1.04	8.52
Completion	0	3.61	5.34	0
COSTS				
Coring costs	$6.28	$8.21	$5.08	$0
Reaming costs	2.39	2.68	3.35	3.07
Drilling costs	27.13	45.50	52.90	52.68
Fuel costs	16.65	15.70	4.14	3.49
Mud costs	3.01	7.92	10.52	1.88
Casing costs	44.44	20.00	24.07	38.83

Working out a balanced rig and arriving at a proper mechanical setup is not difficult. The operator needs sufficient horsepower for hoisting and for rotating and circulating. He must have a power pump capable of giving enough volume of mud at a pressure. The gear end of the pump is usually the bottle neck in this consideration. For minimum requirements we use a figure of 125 ft. per minute for velocity in annular space. With rock bits, we shoot at a figure of 2000 lb. per inch diameter as maximum weight to apply, and supply a drill collar of such total weight that by utilizing 75 per cent of this weight we get the 2000 lb. per inch diameter of the bit. From the bit

numerous other advantages to be gained, it would appear that an 8¾-in. hole would represent the optimum size for digging below the surface with rock bits unless, of course, it is planned to run an intermediate string. For drag-bit drilling, we feel that 7¾ in. represents the optimum size.

All of the drilling figures presented in this paper pertain to the upper Gulf Coast area, extending from Corpus Christi to New Orleans, which involves essentially the use of drag bits, although some rock bits are used. The conclusions drawn apply primarily to this type of drilling and to wells 6000 to 10,000 ft. deep. A true analysis requires accurate and complete data on the

TABLE 4.—*Data of Wells of Different Sizes*

CLASSIFIED AS TO HOLE SIZE AFTER SURFACE PIPE IS SET

Well	Depth	Total Days	Total Cubic Feet	Bit Changes	Feet per Bit	Actual Cubic Feet per Hour	Actual Feet per Hour	Bit, Cost per Foot	Coring, Cost per Foot	Reaming, Cost per Foot	Drilling Time and Bits, Cost per Foot	Fuel, Cost per Foot	Mud, Cost per Foot	Casing,[a] Cost per Foot	Total Cost per Foot	Type Rig
LARGE HOLE																
A-1	8,987	150	12,480	123	73.0	12.84	9.26	$0.794	$1.000	$0.505	$3.71	$1.84	$0.622	$5.20	$12.88	Steam, fuel oil
A-2	7,710	67	8,635	71	108.6	10.05	8.90	0.580	0.141	0.159	3.90	1.04	0.089	2.85	8.18	Steam, gas 15¢ per M cu. ft.
A-3	8,282	75	8,647	41	202.0	11.00	10.53	0.198	0.545	0.046	2.14	1.76	0.096	3.82	8.41	Steam, fuel oil
Average	8,326	97⅓	9,921	78⅓	128.0	11.3	9.56	0.524	0.562	0.240	3.25	1.55	0.269	3.96	9.81	
NORMAL HOLE																
B-1	8,472	82	6,232	78	116.0	6.88	9.35	0.376	0.476	0.226	2.88	1.310	0.062	0.922	5.88	Steam, fuel oil
B-2	8,400	46	5,497	34	276.5	11.42	17.45	0.115	0.119	0.022	1.33	0.001	0.065	0.477	2.01	Steam, gas royalty
B-3	8,197	46	5,698	34	241.0	16.30	23.45	0.177	0.229	0.002	1.05	0.263	0.684	0.612	2.84	Steam, gas 15¢ per M cu. ft.
Average	8,356	58	5,809	49	211.2	11.53	16.75	0.223	0.241	0.083	1.75	0.525	0.273	0.673	3.58	
SEMISLIM HOLE																
C-1	7,451	35	4,313	35	213.0	11.80	20.40	0.156	0	0.115	1.30	0.077	0.041	0.799	2.33	Diesel portable
C-2	8,957	60	4,395	41	357.00	11.30	22.20	0.116	0.244	0.064	1.49	0.135	0.458	0.493	2.88	Diesel portable
Average	8,204	47.5	4,354	38	285.0	11.55	21.30	0.136	0.122	0.089	1.39	0.106	0.249	0.646	2.61	
SLIM HOLE[b]																
D-1	8,293	39	3,708	26	318.9	8.91	20.00	0.086	0	0.118	1.12	0.074	0.076	0.675	2.06	Diesel portable
D-2	7,989	31	3,592	18	443.0	12.42	27.62	0.068	0	0.026	0.83	0.048	0.015	0.680	1.60	Diesel portable
D-3	8,051	37	3,619	19	423.5	10.90	24.30	0.058	0	0.019	0.89	0.065	0.007	0.735	1.72	Diesel portable
Average	8,111	35⅔	3,640	21	395.1	11.14	23.97	0.071	0	0.054	0.95	0.062	0.033	0.697	1.79	

[a] No oil strings included.
[b] These three drilled on same prospect.

entire operation with costs in so far as it is practicable to obtain them. Mere statement of fact without a knowledge of the relationships and factors involved may lead to very erroneous conclusions.

Recognition of improved practices not only in drilling but in completion practices as well should be stressed in an effort to reduce the over-all costs of drilling wells. Practices that were considered highly desirable in the past may be only an additional burden to the operator in the light of present tools and technique.

The primary purpose of this paper is an attempt to set forth some of the work that has been done on the Gulf Coast and direct a little more attention to the possibility of reduction of hole size in other sections of the country where deep drilling is done and where different conditions and regulations combine to create a different set of conditions. If such efforts are followed up, it is hoped that the industry as a whole may be benefited in proportion to any improvement.

Acknowledgment

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Characteristics and Application of an Oil-base Mud

By Horace W. Hindry*

(Los Angeles Meeting, October 1940)

This paper presents the ingredients composing a type of oil-base mud that has been successfully used in drilling oil horizons in California, the effect of ingredient concentrations on physical properties, methods of handling at the well and possible advantages of a waterless drilling fluid with excellent plastering properties.

Introduction

An oil-base mud is a rotary drilling fluid in which oil has been substituted for water as the principal liquid ingredient. In recent years such a mud has been developed and used successfully for drilling the oil horizons of wells in various California fields. There are several types of oil-base mud, but only the type that is currently used to any appreciable extent will be considered at this time.

The oil-base drilling-mud compositions used by Shell Oil Company, Incorporated have been covered by several patent applications on which patents are expected to issue at an early date.

The purpose of this paper is to present data on the fundamental design of the mud; the ingredients used and their specifications; the effect of ingredient concentration on physical properties; the selection of the proper mud; the facilities needed for handling the mud; and a general discussion on drilling with oil-base mud.

In view of the early stage of development of oil-base mud, the great number of variables, and the almost unlimited possible combinations of these variables, which in turn require extensive laboratory study, there are certain irregularities and omissions in the data presented here. However, it is believed that sufficient data are at hand to permit a fairly complete analysis of the characteristics of oil-base muds. In view of the excellent plastering properties of oil-base mud when properly proportioned, its use should: (1) minimize the possibility of impairing the natural flow potentialities of the producing horizon such as that resulting from infiltration of water from water-base muds; (2) permit smaller clearances for setting liners, since the mud sheath has no appreciable thickness; (3) eliminate the possibility of clogging the perforations of the liner with thick mud sheath; (4) facilitate the removal of the mud sheath from the walls of the hole, for its mud sheath has no appreciable strength; (5) assist in drilling through formations, such as "heaving shale," where water wetting appears to be a source of difficulty. (6) permit cores to be obtained without contamination from drilling water.

Fundamental Design of an Oil-base Mud

In the design of any rotary drilling mud it is necessary to select materials that will fulfill the following requirements: (1) act as the liquid medium and regulate the viscosity; (2) impart initial and final plastering properties; (3) give gel strength and structure in order to prevent settling; (4) serve as a weighting material. The

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ingredients selected may serve one or more functions.

In developing an oil base mud it was found that, if properly proportioned, the following materials made a suitable rotary drilling fluid:

1. Stove oil to act as the liquid medium;

2. Oyster shells, limestone or barite, to serve as weighting materials and also to impart the initial plastering properties;

3. Lampblack to give gel strength and structure;

4. Blown asphalt to impart the final plastering properties.

Ingredients

Of the many materials that have been tested those listed above have been found to be the most suitable for the mud under consideration. This does not preclude the possibility that other materials may be found or developed in the future that would function as well or perhaps better than the ones selected. However, based on experience to date, materials conforming to the specifications listed in Table 1 are preferred. In order to facilitate handling in the field, the blown asphalt is cut back with oil so that it may be pumped. In view of the temperature required when melting the asphalt and the low flash point of stove oil, an oil with a high flash point is used for cutting back. The specifications are given in Table 1.

Table 1.—*Specifications of Materials Suitable for Oil-base Mud*

Stove Oil	
Gravity, A.P.I.	38.4°
Color, A.S.T.M.	1½
Flash, Pensky-Marten c.c.	140°F.
Pour point	35°F.
Carbon residue	0.01
Saybolt Universal viscosity at 100°F.	33 sec.
A.S.T.M. distillation:	
Initial boiling point	334°F.
10 % distilled off	336°F.
90 % distilled off	526°F.
Final boiling point	586°F.
Oyster Shells	
Screen analysis	95 % through 100 mesh 85 % through 200 mesh
Specific gravity	2.65
Limestone	
Screen analysis	90 % through 200 mesh
Specific gravity	2.65
Barite	
Screen analysis	97 % through 325 mesh
Specific gravity	4.1
Lampblack	
Oil absorption	0.38 gal. per pound
Specific gravity	1.75
Bulking value	6.75 lb. per gallon
Blown Asphalt	
Penetration (77°F.)	10–20
Melting point, (ring and ball)	225°–230°F.
Cut back[a] with oil of following specifications:	
Gravity, A.P.I.	33.5°
Flash, Pensky-Marten c.c.	170°F.
Saybolt Universal viscosity	at 100°F., 38 sec.
A.S.T.M. distillation	10 % at 448°F. 90 % at 640°F.

[a] The proportions normally used are one part blown asphalt mixed with one and one-half to two parts of oil (by weight).

Effect of Ingredient Concentration on Physical Properties

It is evident that the characteristics of an oil-base mud depend upon the interrelationship and proportions of the various ingredients used. In order to determine the influence of ingredient concentration, a series of tests was made in which the following physical properties were measured under the conditions shown:

Weight: pycnometer; 70°F.

Viscosity: Stormer; 600 r.p.m.; plain cup; 80°F.

Filter loss: low-pressure wall-building tester, 100 lb. per sq. in.; 70°F.; time interval first hour; filtering area, 7 sq. inches.

Settling: 100 c.c. graduates; settling period 18 hr.; 100°F.; determine specific gravity of top half of sample before and after settling period.

The results of these tests are shown graphically on Figs. 1 to 6, inclusive. The units used are: weight in pounds per cubic foot; viscosity in centipoises or the driving weight in grams when the viscosity is above the calibrated range of the viscosimeter; filter loss in cubic centimeters of filtrate lost in the first hour; settling in percentage of the solids settled (the loss of weight in grams of the top half of the sample divided by the original number of grams of solids in the top half, times 100); and concentration in percentage by weight.

In making the tests, it was apparent that permissible variation of the concentration of weighting material, to obtain a mud of

any desired weight, would be slight. Consequently, the concentration of weighting material was maintained constant in each series of tests on mud of a given weight.

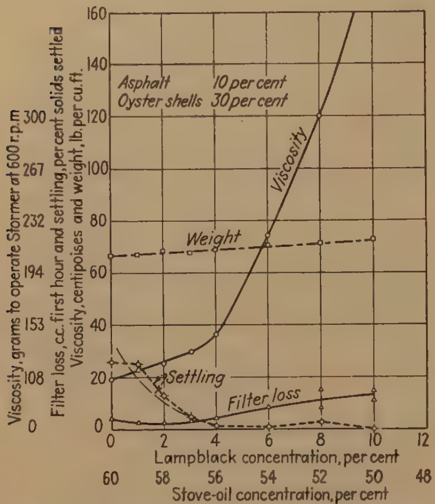

FIG. 1.—EFFECT OF LAMPBLACK CONCENTRATION ON PHYSICAL PROPERTIES OF 69-POUND PER CUBIC FOOT OIL-BASE MUD.

Also, earlier work had demonstrated that lampblack concentration and asphalt concentration were the principal factors in influencing physical characteristics other than weight of the mud. Therefore, tests were made to determine the effect of each of these ingredients on three different muds, 69-lb., 80-lb. and 95-lb. Throughout the various tests, the concentrations of two ingredients were kept constant while the concentrations of the other two ingredients were varied (i.e., when studying the effect of lampblack, the asphalt and oyster-shell concentrations were maintained constant while the lampblack and stove-oil proportions were varied). This method of performing the tests caused the weight of the finished mixture to vary slightly according to the concentrations of the two variable ingredients. If the weight of the finished mixture had been maintained constant it would have been necessary to vary the concentration of three or four of the ingredients of the mud. It is believed that results obtained by allowing the weight of the mixture to fluctuate are more informative,

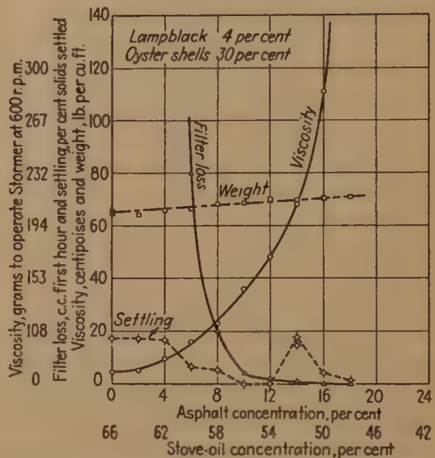

FIG. 2.—EFFECT OF BLOWN-ASPHALT CONCENTRATION ON PHYSICAL PROPERTIES OF 69-POUND PER CUBIC FOOT OIL-BASE MUD.

since the concentrations of only two of the ingredients are varied.

The effect of the lampblack concentration on muds of 69-lb., 80-lb. and 95-lb. per cu. ft. is shown on Figs. 1, 3 and 5, respectively, and the effect of asphalt concentration on muds of corresponding weights is shown on Figs. 2, 4 and 6. The results of the tests as shown on the graphs are for the most part self-explanatory, but there are several results that warrant discussion.

As anticipated, the lampblack concentration is not only the primary factor in determining the settling properties, but it also has a large effect upon the viscosity of the mixture. In addition, it is apparent from Figs. 1, 3 and 5 that the filter loss decreases as the lampblack concentration is increased from 0 to ±2 per cent, and that thereafter the filter loss increases as the lampblack concentration is increased from 2 to 10 per cent. This effect was not expected and at the present time the explanation of this anomaly is not known.

The asphalt concentration of an oil-base mud is the controlling factor in determining the filter characteristics of the mud. It also affects the viscosity and settling properties

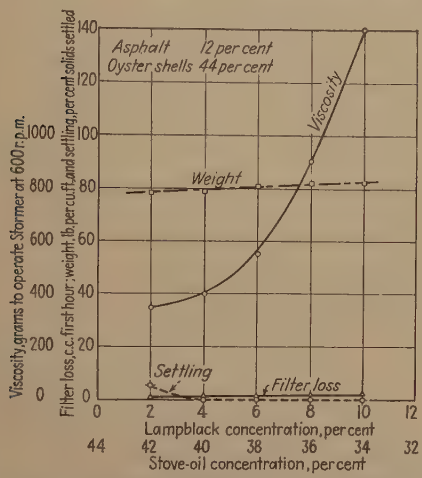

FIG. 3.—EFFECT OF LAMPBLACK CONCENTRATION ON PHYSICAL PROPERTIES OF 80-POUND PER CUBIC FOOT OIL-BASE MUD.

of the mud. In general, a high asphalt concentration in the mud produces a low filter loss, a high viscosity and a low settling rate. An exception was found in the 69-lb. mud when settling rate increased as the concentration of asphalt was raised above 12 per cent, as shown in Fig. 2. The reason for this behavior is not known. Also, it was found that heavy muds require less asphalt to obtain a given filter loss than do light muds.

Although the viscosities of some of the mixtures are unusually high, field tests have demonstrated that moderately high viscosities are desirable to minimize settling. Viscosities as high as 400 grams (grams driving weight to operate Stormer at 600 r.p.m.) have been used successfully in the field.

SELECTION OF THE PROPER MUD

In selecting a mud for use in a well, it is first necessary to analyze the anticipated conditions such as: formation pressure, bottom-hole temperatures, surface temperatures and the amount of oil and gas contamination of the mud. From these it is possible to set up the physical requirements

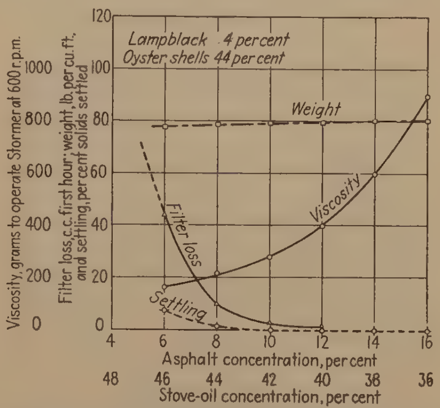

FIG. 4.—EFFECT OF BLOWN-ASPHALT CONCENTRATION ON PHYSICAL PROPERTIES OF 80-POUND PER CUBIC FOOT OIL-BASE MUD.

of the mud, such as: the weight required, the settling properties necessary to prevent excessive settling in the well when circulation is suspended, the maximum viscosity at which the mud can be pumped at surface temperatures (the maximum viscosity is obtained when the mud in the pump suction pits is allowed to cool down to surface temperature while making a round trip of the drill pipe), and the higher viscosity and gel strength that should be maintained to minimize settling if contamination of the drilling fluid by oil and gas is anticipated. After the physical requirements have been determined, it is then possible to select the approximate composition of mud from the data on Figs. 1 to 6. The available materials should then be tested in a mud of this approximate composition to see whether the desired result has been obtained. Slight variations in the physical properties of the materials will produce large variations in the properties of mud produced. In certain cases it may not be possible to produce a mud that will satisfy all of the desired requirements.

Facilities Needed for Handling

The facilities needed for handling oil-base mud at a well are much the same as those required for water-base mud. Additionally, it is advisable to provide storage facilities for mixed oil-base muds, stove oil and asphalt and to maintain a supply of these materials and also lampblack and weighting materials at the well at all times. In cases where oil-base mud is to be mixed at the well, adequate mixing and storage facilities will also be required.

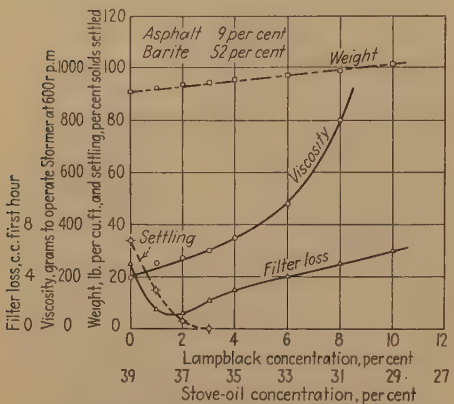

FIG. 5.—EFFECT OF LAMPBLACK CONCENTRATION ON PHYSICAL PROPERTIES OF 95-POUND PER CUBIC FOOT OIL-BASE MUD.

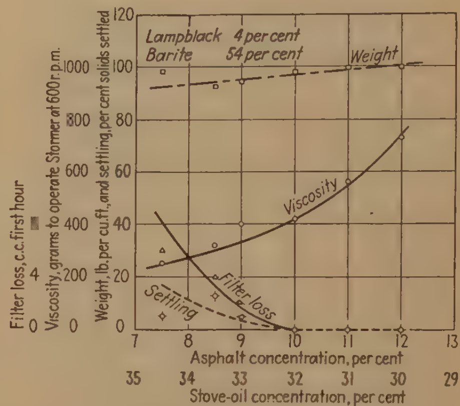

FIG. 6.—EFFECT OF BLOWN-ASPHALT CONCENTRATION ON PHYSICAL PROPERTIES OF 95-POUND PER CUBIC FOOT OIL-BASE MUD.

Where vibrating screens are used, it is necessary to make provisions for washing the screens with stove oil rather than with water. Drill-pipe wipers and sand-line wipers have been found advantageous to minimize waste and contamination of the mud and to promote cleanliness. Rubber deteriorates rapidly in oil-base muds, therefore such parts as pump-valve inserts, pump pistons and drill-pipe protectors usually are made of oil-resistant rubber substitutes. Oil-base mud is an inflammable material and precautions should be taken to minimize fire hazard.

Drilling with Oil-base Mud

Normally oil-base muds require very little attention while they are in use in a well. The occasional small adjustments that are required can be effected by the addition of the proper materials. However, if any major adjustments are necessary, care should be taken to preserve or re-establish the proper interrelationship between the ingredients.

Precautions should be taken to prevent the contamination of the mud with water or water-base mud. Small quantities of water or clay do not affect the physical properties, but when large quantities of water (±15 per cent) are present the quality of the mud is apt to be seriously impaired.

When oil-base muds are subjected to temperatures above 200°F. for a period of 4 or 5 hr. their physical properties are damaged. Neither the reason nor the cure for this condition is known.

Oil-base muds have very little tendency to gas-cut; consequently it is permissible to maintain higher viscosities in the muds to minimize the chances of settling in the bottom of the well when circulation is suspended.

Electrical logs have been successfully made in holes filled with oil-base mud by the use of special electrodes to contact the walls of the hole. The logs obtained were

satisfactory for correlative purposes, although at present insufficient data have been obtained to determine whether water sources can be located successfully.

In most cases the drilling rates with oil-base muds are slightly slower than with water-base muds.

Upon completion of a well the oil-base mud can be stored for re-use but special precautions should be taken to prevent any contamination. Usually very little reconditioning is required to prepare the mud for re-use in another well. At a storage or mixing plant it is quite easy to make large variations in the weights of the mud (from 69 to 80 lb. per cubic foot or from 80 to 69 lb. per cubic foot), by merely adding the ingredients necessary to produce the desired composition.

The costs for drilling with oil-base muds are largely determined by the amount of care exercised in preventing waste and contamination of the mud. In general, the costs are higher than when drilling with water-base mud.

DISCUSSION

W. R. Kelley,* Los Angeles, Calif.—The subject of oil-base muds has received some study from at least several operators. Mr. Hindry's paper offers some very helpful data for anyone attempting its use.

The author makes a distinction between initial and final plastering properties of mud and names the ingredients that contribute to these properties. The mechanics of mud-cake formation may suggest these terms. However, I wonder if this can be explained further by saying that a distribution of particle sizes (shapes as well) helps to determine the minimum filter loss and cake thickness. The nature of the filter medium would determine requirements for effective particle size. For example, a sand composed essentially of coarse grains would require presumably some of the larger and flaky oyster-shell particles to minimize the loss of other ingredients.

I believe some graphic data on mud-cake thickness for given filter losses or percentage of mud solids by volume in the mud itself as well as in the mud cakes would suggest filter-loss requirements or limits.

* Engineer, General Petroleum Corporation of California.

Chapter II. Engineering Research

Screening Effect of Gravel on Unconsolidated Sands

By Ben Gumpertz*

(Los Angeles Meeting, October 1939)

The important factors in any study of the screening of sand with a gravel envelope, as applied to use in oil wells, are: (1) sand size and shape, (2) gravel size and shape, (3) ratio of gravel size to sand size, (4) flow velocity, (5) viscosity of the fluid.

Perhaps the first extensive investigation of the function of gravel in screening sand was performed by Coberly and Wagner,[1] from which the following conclusion was drawn: "The diameter of the largest grains in a single classified sand suitable for gravel packing is approximately 13 times the grain size at the ten-percentile analysis of the formation sample." This applies to sands classified by Tyler screens and is for gravel grains of the maximum size that could be used to form a stable bridge. Field practice has shown that the screening effect of a given gravel for a given sand apparently varies with the flow velocity.[2] Also, it has been assumed by some operators that the thickness of the walls of the gravel envelope surrounding the well has little effect upon the screening process. It is thought by others that a narrow envelope of gravel might form an ineffective screen. Thus the purposes of this work are:

1. To investigate the effect of gravel-sand size ratio upon screening action under the condition of varying flow velocities.

2. To investigate the effect upon screening action of varying the thickness of the gravel screen.

3. To investigate sand migration in the gravel screen and the effect of flow velocity and gravel size upon sand migration.

Description of Apparatus

In an attempt to reproduce field conditions for the purposes of this investigation, a flow tube was constructed, according to the manner of Uren,[3] to represent a radial drainage segment of an oil sand.

To arrive at the dimensions of the flow tube, a radial drainage segment of rectangular cross section was assumed to define an area of 2 sq. in. on the face of a well 6 in. in diameter. From this the dimensions of the segment were calculated out to a distance of 5 ft. from the face of the well. By computing cross-sectional areas at a number of sections along the rectangular segment and transforming these areas into the circular form, a drainage cone was obtained having everywhere the same cross-sectional area as the drainage element of rectangular cross section.

To construct the apparatus, two sections of pipe of 7⅝-in. inside diameter, one 13 in. and the other 4 ft. long, were joined by a bolted flange. A mandrel having the dimensions of the drainage cone was centered in the pipe and a neat cement mixture was cast around it. A protective gasket was placed between the two sections of pipe so that the cement body could be separated at that point. When the mandrel was withdrawn a drainage cone was obtained (Fig. 1).

A round slotted screen, which could be screwed up against the end of the drainage cone, held the gravel in place.

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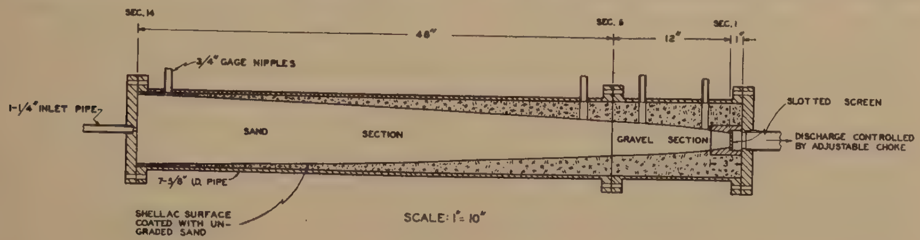
[1] References are at the end of the paper.

The purpose of the short section of the tube was to contain the gravel serving as a screening medium; the long section of the ungraded sand. In the gravel section this would have the effect of preventing migration of the sand along the walls of the tube.



FLOW AREA
SECTION DIMENSIONS

SECTION	DIAMETER INCHES	AREA SQ. IN.
1	1.60	2
5	3.56	10
14	7.32	42

FIG. 1.—FLOW TUBE FOR GRAVEL-PACK INVESTIGATION.

tube contained the sand representing the producing formation. The gravel section of the tube could be removed from the long section, the gravel changed, and the gravel

The tube was mounted on a pivot, so that it could be swung into the vertical position for packing. Four pressure gauges were provided, one at each end of the tube

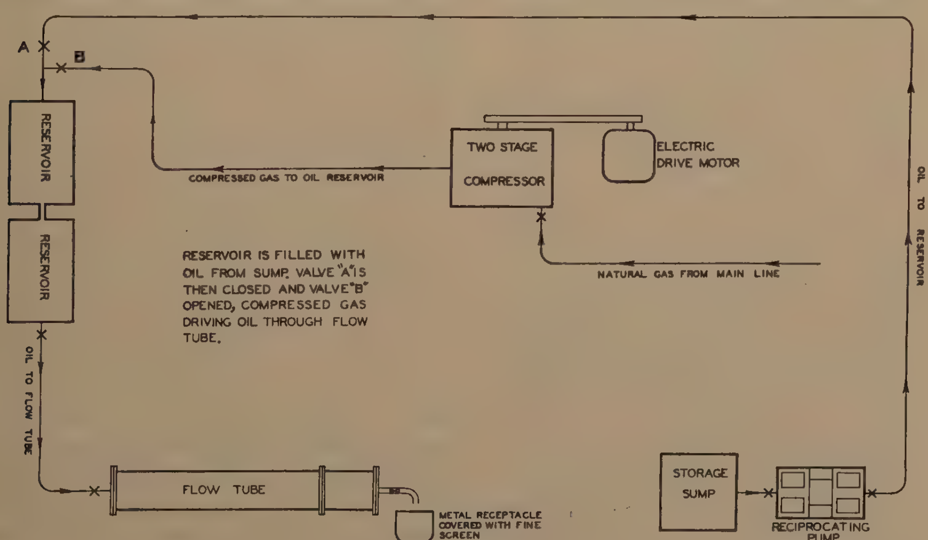


FIG. 2.—FLOW CHART.

section replaced without the necessity of changing the whole sand body.

The cement surface of the drainage cone was brushed with shellac and coated with and two adjacent to the sand-gravel interface (one on each side of it).

Pressure was provided by a Rix two-stage compressor. Two pieces of 10-in.

casing, each 4 ft. long and joined by a short length of ¾-in. pipe, comprised the oil reservoir. The compressor, oil reservoir, and flow tube were connected in series (Fig. 2).

Metal receptacles fitted with wire screens were provided to receive the oil and to separate from it any sand that might be produced. Other equipment consisted of thermometers and graduate cylinders, with a stop watch for measuring the rate of flow of the oil.

Experimental Procedure

In packing the flow tube, the sand to be used was mixed with a predetermined amount of oil, the tube was raised to the vertical position on its pivots, and the sand tamped into the tube. The short section of the tube was then packed with gravel, the long section lowered into the horizontal position, and the two sections bolted together.

Calibration of the tube (determination of the rate of flow for different pressures and choke sizes) was accomplished by leaving the choke size constant for a series of rate-of-flow measurements at different pressures. This procedure was repeated for a number of different choke sizes.

The calibration was performed to enable measurement of the desired quantities at comparable flow velocities. However, in performing the actual experiments the flow velocities obtained did not always correspond with the calibration data. This was due perhaps to the fact that, in calibrating the flow tube, sufficient time may not have been allowed between runs at different pressures, with the result that the pressure was changing along the length of the tube during the calibration runs. Lag in the pressure gauges and probable mechanical errors in them may account in part for this difference, although the gauges were calibrated frequently. It was also difficult to duplicate flow velocities in different runs because pressure control was delicate at the low pressures used in most of the runs.

For making an experimental run, the oil reservoir was filled and compressed natural gas was admitted until the desired pressure was attained. The oil was then admitted to the flow tube, the adjustable choke having been previously set for a given rate of flow. The compressor was operated for the duration of the run, compressed gas being supplied to the oil reservoir at a rate adjusted to keep the pressure as nearly constant as possible.

The oil was allowed to flow for a measured number of minutes from the tube through a fine screen into a receptacle. The screen held any sand that might be produced. The receptacles and the screens were changed at definite time intervals during one run, so that the time-rate of sand production might be observed. The quantity of oil in each receptacle was measured and the flow velocity of the oil for that time interval was computed at the face of the well. This procedure was repeated at different velocities, using separately two graded sands of different grain size, with graded gravels of four different sizes as the screening mediums.

Although the driving force was derived from soluble natural gas under compression, the oil was essentially "dead," the amount of gas going into solution being negligible. The oil was of 22° A.P.I. gravity and 1.14 poises absolute viscosity.

For the first series of runs the sand section of the tube was packed with Monterey Beach sand of 35 to 48 grain size to a porosity of 36.7 per cent. The gravel section was packed with 8 to 10-mesh gravel, and the sand production was observed at different flow velocities. The porosity of the gravel never varied more than 0.1 per cent from 43.4 per cent.

Observations were continued with the 35 to 48 sand at different velocities, using separately two more gravels of 6 to 8 and 4 to 6 grain size. The same procedure was

repeated with a 48 to 65 grain size white river sand packed to a porosity of 42.2 per cent. All grain sizes refer to Tyler Standard screens.

The grains of the Monterey Beach sand varied in shape from oblong to those approaching roundness. The corners and edges were well rounded. The white river sand consisted almost entirely of quartz grains, subangular, fairly well rounded to well rounded.

The grains of the 3 to 4 and 4 to 6 grain-size gravel were angular, with the corners and edges mostly well rounded. The grains of the 6 to 8 and 8 to 10 grain-size gravels were subangular, with mostly well rounded corners and edges.

After each run the sand body was carefully inspected at the interface and back into the tube for some distance. Before a new run was made the sand was cleaned out back into the tube until firm, undisturbed sand was encountered. This part of the tube was then repacked with fresh sand.

During each run the rate of oil production and the sand production were measured at intervals of 5, 10, 15, 25, and 40 min. Flow velocities were computed for the periods of maximum rate of oil production, so that the velocities listed in Tables 2 and 3 represent the maximum flow velocities for each run.

The gravels used as the screening mediums were each graded to a single classification.

Sand Migration

To investigate sand migration in the gravel screen under the conditions of the various tests described herein, the gravel section of the flow tube was divided into 12 imaginary sections along the longitudinal axis of the tube, each 1 in. long. These imaginary sections were numbered consecutively from 1 to 12, beginning with the section adjacent to the sand-gravel interface. Beginning with the second section, the contents of every third section (the second, fifth, eight, and eleventh) were removed from the tube, the sand was separated from the gravel and the weight of sand per unit volume of the section from which the sand came was computed.

Effect of Length of Gravel Screen

To determine the effect of the length of the gravel screen, a number of runs were made as before, except that the gravel section of the tube was packed with gravel to depths of 10 in., 6 in., and 3 in. The longitudinal distribution of sand in the gravel was not measured for these runs. Another sand was prepared for this series of runs by mixing graded portions of the Monterey Beach sand and the white river sand.

Experimental Results

Gravel-sand Size Ratio and Velocity Effect

To establish a practical range of flow velocity, assume that a well of 6-in. diameter produces 1000 bbl. of oil per day from a sand 10 ft. thick. The velocity of the oil at the face of such a well would be approximately 4×10^{-3} ft. per sec., which is to be taken in this paper as the upper limit of the practical velocity range.

To compute the ratio of gravel size to sand size, the method of Coberly and Wagner[1] was used, which means that the diameter of the gravel grains was taken as the width of the opening in the screen through which these grains passed, while the diameter of the sand grains was

Table 1.—*Gravel-sand Size Ratios*

Gravel Grain Size	Sand Grain Size	
	35–48	48–65
8–10		11.3
6–8	11.3	16.0
4–6	16.0	22.6
3–4	22.6	

taken as the width of the openings in the screen on which these grains were retained.

Consider first runs 1 and 2 and runs 13 and 14, Table 2. The sand used in runs 1 and 2 was Monterey sand of 35 to 48 grain size; the ratio of gravel to sand size was 11. In those two runs the flow velocities were tremendously greater than those encountered in actual practice, yet the gravel formed a very effective screen, allowing hardly a trace of sand to go through at these excessive velocities.

The flow velocities in runs 13 and 14, while much lower than in runs 1 and 2, still greatly exceeded the practical range. The sand used in these runs was white river sand of 48 to 65 grain size and the ratio again was 11. In both of these runs an effective bridge was formed in a short period of time, after which no sand was produced.

In runs 7, 11, 12 and 9 (in order of increasing flow velocity) the 48 to 65 white river sand was also used, the ratio being 16. The velocities for runs 7 and 11 are close together and well within the practical range. In these two runs an effective screen was formed. However, when the flow velocity was increased to a point near the upper limit of the practical range of velocity, the gravel at a ratio of 16 ceased to form an effective screen. A further increase in velocity increased the production of sand through the gravel. Thus it is evident that at a gravel-sand size ratio of 16 the flow velocity that would limit the use of this gravel as a screening medium lies somewhere between 1.25×10^{-3} ft. per sec. and 4.0×10^{-3} ft. per sec., being probably close to the smaller value. Runs 3 and 4 also serve to demonstrate the fact that the gravel-sand size ratio of 16 is unsatisfactory outside of the practical range.

TABLE 2.—*Comparison of Gravel-sand Size Ratios, Flow Velocities and Screening Ability*
12-INCH GRAVEL PACK. RUNS GROUPED ACCORDING TO SIZE RATIOS

Run	Gravel Size, In.	Sand Size, In.	Ratio	Flow Velocity, Ft. per Sec. at Well Face	Remarks
1	0.131	0.0116	11.3	135.0×10^{-3}	Made only a trace of sand. Satisfactory screen.
2	0.131	0.0116	11.3	115.0×10^{-3}	Made hardly a trace. Good screen.
13	0.093	0.0082	11.3	16.6×10^{-3}	Good screen.
14	0.093	0.0082	11.3	16.8×10^{-3}	Good screen.
3	0.185	0.0116	16.0	6.1×10^{-3}	Gradual decrease in sand production but continued to make a little sand. Unsatisfactory.
4	0.185	0.0116–	16.0	321.0×10^{-3}	Poor screening action.
7	0.131	0.0082	16.0	1.2×10^{-3}	Good screening action.
9	0.131	0.0082	16.0	11.5×10^{-3}	Not a good screen.
11	0.131	0.0082	16.0	1.2×10^{-3}	Very good screen.
12	0.131	0.0082	16.0	4.3×10^{-3}	Gradually bridged but continually made very small amount. Doubtful.
5	0.263	0.0116	22.6	19.3×10^{-3}	Gradually bridged to form a good screen.
6	0.263	0.0116	22.6	105.0×10^{-3}	Unsatisfactory.
15	0.185	0.0082	22.6	2.5×10^{-3}	Very poor screening action.
16	0.185	0.0082	22.6	1.0×10^{-3}	Continually made small amount of sand. Unsatisfactory. At end of this run flow rate was doubled without stopping flow. Within a short time sand started to flow freely.

Run 5 presents an anomaly that the writer cannot explain. With a gravel-sand size ratio of 22 an effective bridge evidently was formed at a velocity far out of the practical range. This is the only case of its kind encountered throughout the work. Yet run 5 gave every evidence of gradually forming a stable bridge and becoming an effective screen.

In run 15, with a velocity at the well face of 2.5×10^{-3} ft. per sec., a large amount of sand was produced in the first 4 min. of the run, after which the sand flowed freely through the gravel. The gravel-sand size ratio in this case was 22.

For the next run (16) at the same ratio, the flow velocity was reduced by more than one-half to 1.0×10^{-3} ft. per sec. In this run, although the value of the gravel to

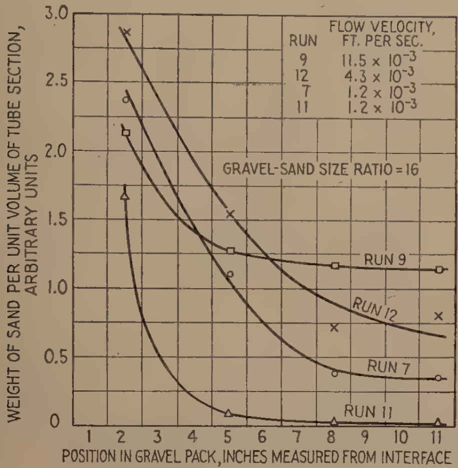


FIG. 3.—DISTRIBUTION OF SAND IN GRAVEL PACK.

serve as a screen at this velocity is doubtful, only a small amount of sand was produced steadily, in contrast to the freely flowing sand of run 15. After producing a small amount of sand steadily for some minutes, when apparently there would be no further bridging action, the flow velocity again was doubled without stopping the run. Within a short period of time sand again started to flow freely.

Thus the gravel with a size ratio of 11 to that of the sand is seen to operate successfully as a screen over the entire velocity range, and considerably above it, while the gravel with a size ratio of 16 to that of the sand is seen to operate successfully as a screen only over the lower regions of the practical velocity range.

Sand Migration in Gravel Screen

The weight of sand per unit volume of the gravel section was measured along the length of the gravel section of the flow tube for each run to and including run 16. These measurements are represented graphically in Figs. 3 and 4.

The character of the curves seems to bear no relation whatever to the gravel-sand size ratio or to flow velocities. In Fig. 3 the curve for run 7 falls above that

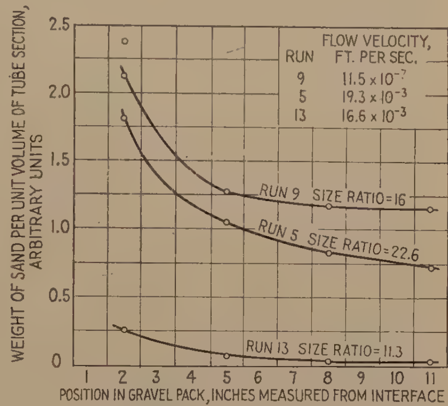


FIG. 4.—DISTRIBUTION OF SAND IN GRAVEL PACK.

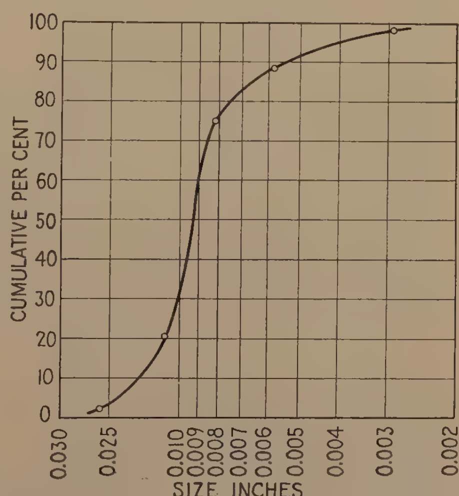


FIG. 5.—DISTRIBUTION OF GRAIN SIZE, MIXED SAND.

of run 11. Though the velocity for run 7 is very little below that for run 11, the curves are displaced by a comparatively large distance. Likewise, the curve for run 9 crosses the curves for runs 7 and 12, both having lower flow velocities than run 9. The curves of Fig. 3 all represent runs with the same gravel-sand size ratio, at different velocities.

The curves of Fig. 4 represent runs at velocities of approximately the same magnitude but with different gravel-sand size ratios. Neither do they fall in any particular order, since the curve for run 5, the run having the highest flow velocity and the largest ratio of the three, falls between the other two curves. However, the curves do show that the bridging process is cumulative back into the gravel. They also show that in no case did bridging not greatly affect the screening action of the gravel.

Considering the 3-in. gravel pack with gravel-sand size ratio of 16 (Table 3), it can be seen that screening action was satisfactory at a velocity of 1.6×10^{-3} ft. per sec., while at a velocity of 4.0×10^{-3} ft. per sec. the screening action became of doubtful value. This action corresponds closely to that of the 12-in. gravel pack with gravel-sand size ratio of 16.

TABLE 3.—*Comparing Results of Different Lengths of Gravel Packs*

Run	Length of Gravel Pack, In.	Gravel Size, In.	Sand Size, In.	Ratio	Flow Velocity, Ft. per Sec. at Well Face	Remarks
17	10	0.185	ungraded	14.2[a]	0.8×10^{-3}	Produced no sand. Good screening action.
18	10	0.185	ungraded	14.2[a]	2.2×10^{-3}	Not a good screen.
19	10	0.185	ungraded	14.2[a]	3.6×10^{-3}	Unsatisfactory.
20	6	0.131	0.0082	16.0	0.6×10^{-3}	Bridged in short time. Satisfactory screen.
21	6	0.131	0.0082	16.0	2.3×10^{-3}	Bridged to form satisfactory screen.
22	6	0.131	0.0082	16.0	3.9×10^{-3}	Continually made trace. Satisfactory.
23	6	0.131	0.0082	16.0	7.5×10^{-3}	Continually made small amount. Unsatisfactory.
24	6	0.131	0.0082	16.0	10.5×10^{-3}	Unsatisfactory.
25	6	0.131	ungraded	10.0[a]	10.5×10^{-3}	Gradually bridged until very small amount of sand was being made. Doubtful.
26	6	0.131	ungraded	10.0[a]	3.5×10^{-3}	Bridged in short time until making only very slight trace of sand. Satisfactory.
27	6	0.263	ungraded	20.0[a]	1.2×10^{-3}	Made large amount of sand. Unsatisfactory.
28	3	0.131	0.0082	16.0	1.6×10^{-3}	Made slight trace. Satisfactory.
29	3	0.131	0.0082	16.0	4.0×10^{-3}	Continually produced small amount. Unsatisfactory.
30	3	0.131	0.0082	16.0	6.2×10^{-3}	Unsatisfactory.
31	3	0.131	0.0082	16.0	0.8×10^{-3}	Satisfactory screen.
32	3	0.131	ungraded	10.0[a]	1.8×10^{-3}	Bridged to produce no sand. Good screen.
33	3	0.131	ungraded	10.0[a]	4.6×10^{-3}	Gradually bridged until a very small amount of sand was being produced. Doubtful.

[a] Ratio of size of gravel to sand size at 10 per cent point.

begin at the sand-gravel interface to prevent sand from entering the gravel.

Screening action in a gravel, then, appears to be due to the bridging of the larger grains of sand against the gravel, with cumulative bridging of the smaller grains of sand against the larger. It appears from this action that the necessary width of gravel to form an effective screen could be measured in terms of a few grains of the gravel, or it is that width just sufficient to start bridging action.

Variation of Length of Gravel Pack

Table 3 shows that for graded sands the length of the gravel pack above 3 in. does

A gravel-sand size ratio of 10 is the largest that will successfully screen the ungraded sand over the full range of practical flow velocities. The sand size in this case is taken as that at the 10 per cent point of analysis, 0.013-in. dia. (Fig. 4). With a gravel-sand size ratio of 14 the screening action becomes doubtful at a flow velocity of 2.2×10^{-3} ft. per sec. This is with a 10-in. gravel pack. Thus to cover the whole practical range of flow velocities, a gravel-sand size ratio of 10 would be preferable for screening this sand, while for velocities below 0.8×10^{-3} ft. per sec. at the well face a gravel-sand size ratio of 14 would be satisfactory.

The limiting width of the walls of a gravel pack necessary to form a satisfactory screen, which within the practical range of velocity is below 3 in., was not reached in this work. However, the results of this particular series of tests would tend to confirm the previous assumption that the width of the pack need be only sufficient to start bridging action.

Conclusions

1. The largest grains of a gravel to be used for screening unconsolidated sand over the entire range of flow velocities should bear a diameter ratio of 11 to the diameter of the sand at the 10 percentile analysis. For velocities below 1.0×10^{-3} ft. per sec. at the well face this ratio can be increased to 16. This in a large measure agrees with the theory and results of Coberly and Wagner.[1]

2. The minimum width of the walls of a gravel pack, to give good screening action, seems to be that just sufficient to start bridging action. This width may be that of several grains of the gravel.

3. In a gravel pack there is no relation between flow velocity and gravel-sand size ratio, and the distribution of sand in the pack. Some sand was found to migrate the length of the pack in all cases.

Acknowledgments

The writer wishes to express gratitude for the assistance offered during the course of this work, to Mr. E. L. Davis of The Texas Company (California) and to Mr. E. M. Wheeler, graduate student at the University of California. Thanks are due especially to Prof. L. C. Uren, of the Petroleum Engineering Department of the College of Mining, University of California, and to Mr. Bachman, mechanic of the Mining Department of the University of California, whose aid in the construction of the apparatus was invaluable.

References

1. C. J. Coberly and E. M. Wagner: Some Considerations in the Selection and Installation of Gravel Pack for Oil Wells. A.I.M.E. *Tech. Paper* 960 (1938) 1.
2. Information from Mr. E. L. Davis, The Texas Company (California), Los Angeles, California.
3. L. C. Uren and E. J. Bradshaw: *Trans.* A.I.M.E. (1932) 98, 438–466.

DISCUSSION

C. J. Coberly,* Huntington Park, Calif.—Mr. Gumpertz has added some valuable material on a subject that is of particular interest in unconsolidated sand areas of the Gulf Coast and California.

The difficulty of getting the sand face in contact with the gravel without some initial cavity that has to be filled in after fluid flow starts suggests the advisability of filling the short section first, assembling the long section in place and then filling and tamping the sand over the gravel. This may be the reason for some inconsistencies in bridging, and particularly the migration of sand through the gravel. In tests made by Coberly and Wagner, no evidence was found of sand migration beyond two or three gravel grain diameters. Some variations in results are to be expected in bridging tests, owing to the shape factor of both the sand and gravel grains. For this reason averages are desirable from a number of runs under the same conditions to permit accurate conclusions, particularly in regard to amount of sand that migrates into the gravel. Mr. Gumpertz's third conclusion would be in some doubt because of lack of sufficient data to be certain of an average result.

E. M. Wagner,† Huntington Park, Calif.—Some experimental inconsistencies were noted by Mr. Gumpertz. These might be explained by considering three items: method of packing the sand in the tube; mechanism of bridge formation (bridging range); and effect of grain shape (also might be included in bridging range). The gravel and sand sections of the tube were packed and then put together. This is bound to cause some shifting of the sand at the interface, as the grains will not be stably interlocked at the first contact. As the pressure differential across the interface is changed by varying flow rates, the sand pack will shift, causing erratic results.

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Since bridging will or may occur over a range of conditions, a single test will not suffice as a basis on which to draw any general conclusions. Different types of bridging will alter the flow conditions.[4,5] The probability of repeating a given bridge is remote. Averages of a number of flow and bridging tests must be used to obtain representative results.

The method of packing the sand also is important. Tamping the sand by vibrating has led to the most reproducible results. Hand tamping has not in general led to reproducibility.

In conclusion 3, some mention of the effect of grain shape should be made. Similarity of grain shape is as important as flow velocity and gravel-sand size ratio in formulating any broad conclusions such as this.

The graphs showing the distribution of sand in the gravel pack would be more useful if the amount of sand in the gravel were expressed as a percentage of the pore space of the gravel, or in some concrete units, as cubic inches per cubic inch, along with the porosity of the gravel pack, so that some idea of the relative amounts of sand and gravel could be obtained.

In discussing the effect of velocity and bridging, it might be pointed out that there are two extremes—a velocity of flow so low that no sand is carried regardless of bridging conditions, and a bridge so stable that no sand is carried regardless of velocity. In the regions explored these conditions seem to be mixed. It would be interesting in interpreting the results to know what the two limits are for some of the sands and oil used.

Mr. Gumpertz has made a considerable contribution in his investigation on the effect of fluid velocity on the stability of sand bridges on gravel beds.

In all work on bridging of unconsolidated sands, there is need for a better definition of what may be considered "bridging." The upper and lower limits of the bridging range need more specific definition than is now in common use. Lacking such definitions, it is difficult to compare results under different conditions. In any event, consideration must be given to the fact that bridging can occur over a considerable range and allowance must be made for this fact when interpreting results of experimental work. Some of the inconsistencies noted in experimental work can be explained if this is done.

It is suggested that the definition of stability of bridging can be approached by making use of the statistical probability of bridging as related to sand size as a function of average size of the openings to be bridged.

Because of the influence of grain shape and size distribution (even in a classified sand of one screen size), it is doubtful whether there are enough elements of similarity present in sands and gravels of different sizes to make more than a rough comparison of the effects of single variables. All variables but the one being investigated must be held in correct dimensional relation to do so. Without such strict control, only broad trends may be defined.

Mr. Gumpertz has investigated the effect of depth of gravel necessary to form a good screen. I do not believe that the function of screen formation is one of depth; rather, it is a surface effect. The only influence of depth is that there must be sufficient depth to take care of the chance occurrence of "cubical" grain packing on the surface among the more stable "hexagonal" packing. There must be enough depth to ensure a "hexagonal" opening behind the "cubical" opening, so that a bridge may form. The minimum depth of well-graded gravel of reasonably spherical grain shape is probably of the order of five grains.

If screening is a depth function when gravel is selected according to the thirteen times rule, the selection of the gravel should be changed to make it a surface function and the definition of a stable bridging range changed to conform to the experimental facts. Otherwise the gravel bed will gradually fill with sand and finally reach a permeability that may be less than if the sand were directly against the liner. Stable bridging might be set at values that allowed continual production of small amounts of fines, which would be transported through the gravel bed and not be dropped out in the continual change of direction of flow through the bed. From the standpoint of the possibility of filling the gravel bed with fines, this bed should be as shallow as is consistent with safety. In prepacked gravel liners, as shallow a bed as is safe is important also from the standpoint of "washing" through the bed.

[4] R. L. Chenault: Experiments on Fluid Capacity and Plugging of Oil Well Screens. Amer. Petr. Inst. Drill. and Prod. Practice (1938) 292–306.

[5] C. J. Coberly: Selection of Screen Openings for Unconsolidated Sands. Amer. Petr. Inst. Drill. and Prod. Practice (1937) 189.

In selecting gravel to hold sand of a given size, it would appear that the maximum possible opening between the grains would govern and not the average openings. If the maximum size is used, the data resulting are not as much restricted to the particular screen scale used, but are of more general nature.

It is also important in the study of bridging to make use of some method of eliminating as many of the indeterminate variables as possible. It appears desirable to use spherical grains of some sort for primary investigations for formulation of general rules, and then to shift to sands and commercial gravels to reduce to commercial usefulness the rules and trends so discovered.

Colloid Chemistry of Clay Drilling Fluids

By A. G. Loomis,* Member A.I.M.E., T. F. Ford* and J. F. Fidiam*

(Galveston Meeting, October 1939)

It is only within the past 10 years that serious attempt appears to have been made to improve rotary drilling fluids by the application of the principles of colloid chemistry, although the use of chemicals to control the rheological properties of clay slips has long been known in the ceramic industry. The main difficulty apparently lay in the lack of a complete analysis of all of the functions of a drilling fluid in the drilling of the well, together with the lack of adequate consideration of how colloid science could be applied to secure these ends, and particularly how apparent antithetical properties of the fluid could be compromised. Thus one analysis[1] of the many requirements of a drilling fluid proved conclusively that the viscosity should be low, in order that cuttings and entrained gas might be eliminated efficiently in the settling ditch, while the loss in carrying capacity accompanying low viscosity could be regained by increasing either the density of the mud or the upward velocity of the mud stream in the annular space of the well, and the danger of sticking of the drill stem due to rapid settling in case of enforced suspension of drilling operations could be eliminated by enhancing the thixotropic properties of the fluid.

The desired properties of the drilling fluid having thus been established, it was a natural step to treat the fluid with viscosity-reducing chemicals, such as salts of weak organic acids[1,2]—for example, sodium tannate or gallate—and to adjust the pH to the alkaline side to such a degree of thixotropy as would give low viscosity and low yield point under the conditions of flow prevailing in the settling ditch, but rapid gelation and high yield point when quiescent in the annular space during shutdowns. In fact, flow in the settling ditch should be just short of turbulent while flow in the well, together with the flow of mud past the cuttings, is practically always turbulent. The use of chemicals other than those mentioned, such as Calgon (sodium hexametaphosphate) and certain other phosphates together with sodium tannate, has now become standard practice and it is the consensus that this method of treatment has proved to be an important step in the development of the art of drilling oil wells.

It is safe to assume that the application of colloid chemical principles can also help in solving other outstanding problems of drilling fluids, such as the development of cheaper and more efficient viscosity reducers; the development of chemicals that do not lose their effectiveness in a short time during drilling operations; the finding of chemicals to preserve the plastering properties of muds when concentrated brines are encountered or in drilling through salt beds; improvement in the plastering properties of poor muds by further deflocculation, and, conversely, the prevention of excessive deflocculation of certain marine shales sometimes encountered; the preparation of muds suitable for the successful drilling of heaving shale formations; the finding of chemicals to treat the mud to prevent or to diminish lost circulation; the development of muds that will not impair

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* Shell Development Co., Emeryville, California.

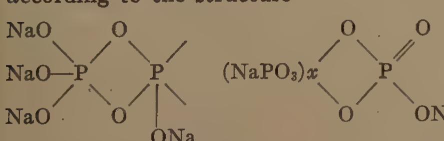
[1] References are at the end of the paper.

the producing zones; muds that will consolidate loose formations and shut off water horizons without the use of casing; and, finally, muds to withstand the high temperatures to be encountered in the deep-drilling program of the future.

It is the purpose of this paper to examine in as fundamental a manner as possible the colloid chemistry of clay suspensions as we know it today, with the hope that the mechanisms proposed will help to point the way to the solution of the problems just mentioned. Experiments described herein develop the view, which has also been suggested by Garrison,[3] that viscosity-reducing chemicals are adsorbed on specific surfaces of clay particles and that they reduce the viscosity of suspensions by destroying the aggregation of the particles into structures. This view has been extended with more detailed consideration of the chemical and electrical properties of the different crystal faces of clay particles to account for most of the phenomena encountered with clay suspensions.

Viscosity Reduction Produced by Various Chemicals

Viscosity reduction produced by sodium silicate, sodium tannate, Calgon and sodium pyrophosphate is shown by the curves of Fig. 1. In Fig. 2 similar curves are given for a series of sodium polyphosphates of which the pyrophosphate is the first member. Sodium pyrophosphate is one of the most effective of the viscosity reducers.[4] The polyphosphates[5] have the general formula $Na_nP_{n-2}O_{3n-5}$ and probably differ only in the length of the PO_2 chain according to the structure



Viscosities were measured at room temperature with the Störmer viscosimeter with suspensions that had been aged for several weeks. The clay was bentonitic, found near Frazier Mountain, California, and used in the Los Angeles area to make drilling mud.

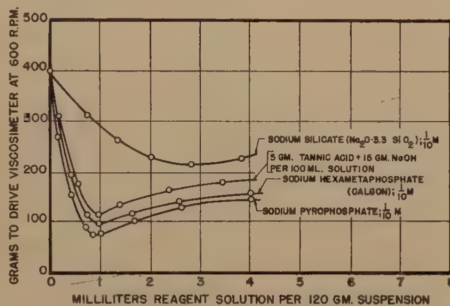


Fig. 1.—Reduction of viscosity produced by various chemicals. Curves corrected for dilution.

Evidence for Adsorption of Viscosity-reducing Chemicals in the Clay-water Interface

The amount of sodium tetraphosphate required to reduce the viscosity of Frazier Mountain clay is greater per gram of clay for fine fractions than for coarse fractions as obtained in the De Laval and Sharples centrifuges. The analyses of these fractions are almost identical, which appears to eliminate any explanation based on differences of chemical composition. For graded bentonite fractions also the amount of tetraphosphate required increases with decreasing particle size. This chemical, therefore, seems to have at least its initial effect on the outside surfaces of the particles, but apparently in time it may diffuse into the particles, since treated suspensions are observed to revert to their original viscosities after standing for several hours or days, especially if there is agitation.

It is found that among the polyphosphates the pyrophosphate, which has the lowest molecular weight, produces the least permanent effect, and that as the molecular weight increases to the decaphosphate there is a corresponding increase in the perma-

nence of the viscosity lowering, which suggests an increasing difficulty of diffusion into inner particle surfaces or increasing tenacity of adhesion to the external surfaces as the size of the adsorbed molecules is increased.

These observations are of considerable interest in connection with the necessity for repeated chemical treatments of the mud as the well is being drilled. It is realized of course that addition of new mud-forming material, together with an increase in the fineness of the clay as a result of grinding by the bit and drill stem, are important factors in this process, but diffusion of the viscosity-reducing chemical into the clay particles is also important and further study of the entire problem is necessary to evaluate its component parts properly.

A more direct proof that viscosity-reducing chemicals are adsorbed on clay particles, and that ordinary salts are not adsorbed in accordance with the thesis of this paper, is afforded by analysis of the supernatent liquors obtained by centrifuging muds treated with sodium tetraphosphate and sodium chloride. Sufficient tetraphosphate was used to cause maximum lowering of viscosity and sufficient salt to cause maximum gelation. It was found that the tetraphosphate is adsorbed quickly while the salt is not adsorbed; the latter must therefore cause gelation because of an ionic effect.

The amounts of the polyphosphates required to produce maximum reduction of

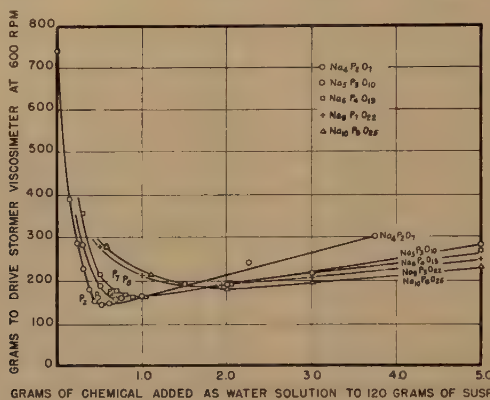


FIG. 2.—REDUCTION OF VISCOSITY PRODUCED BY SODIUM POLYPHOSPHATES. CURVES CORRECTED FOR DILUTION.

viscosity when added as 10 per cent solutions to 120 grams of suspension containing 14 grams of clay, as calculated from Fig. 2, are, approximately:

For	Prepared by Fusing	Mols
$Na_4P_2O_7$		0.00021
$Na_5P_3O_{10}$	$Na_4P_2O_7$ + 1/6 $Na_6P_6O_{18}$	0.00019
$Na_6P_4O_{13}$	$Na_4P_2O_7$ + 1/3 $Na_6P_6O_{18}$	0.00018
$Na_9P_7O_{22}$	Na_3PO_4 + $Na_6P_6O_{18}$	0.00020
$Na_{10}P_8O_{25}$	$Na_4P_2O_7$ + $Na_6P_6O_{18}$	0.00018

The figures suggest that these compounds are oriented in an interface, and that they produce equal effects per molecule because they cover equal areas per molecule.

The amount of tannic acid required to produce the maximum reduction of viscosity in 120 grams of suspension containing 7 grams of clay as calculated from Fig 1 is 0.002 times the formula weight of tannic acid, $C_6H_7O_6[(COC_6H_2(OH)_2OCOC_6H_2(OH)_3]_5$, and the cross-sectional area of this molecule is probably about 160 sq. Å., or five times 32 sq. Å., the approximate area of one digalloyl group. The amount of pyrophosphate required for the same suspension is 0.00009 mol, and the cross-sectional area of this molecule is probably about 25 sq. Å. The total monomolecular film areas as calculated from these figures are: for the tannate, 20 × 10^{20} sq. Å. and

for the pyrophosphate, 15×10^{20} sq. Å. Evidently these chemicals are adsorbed on the same surfaces.

In these experiments Baker's c.p. sodium pyrophosphate was used. Samples of sodium tetraphosphate were prepared in the laboratory by fusing pyrophosphate and hexametaphosphate (Calgon) and by fusing orthophosphate and hexametaphosphate as described by Mellor.[6] The triphosphate, heptaphosphate and octaphosphate were prepared as indicated in the foregoing table. Mixtures of pyrophosphates and hexametaphosphates in the proportions fused to make these polyphosphates did not have the same reducing effect on the viscosity but were more active on a weight basis.

Effect of Chemical Treatment on Rheological Properties of Clay Gels

Thixotropy.—The most distinctive property of clay suspensions is their thixotropy, which is defined[8] as an isothermal reversible sol-gel transformation. This definition does not specify the time for the transformation nor the relative change in the gel strength but from a practical standpoint it is essential that the change occur at a moderate rate, measured in the order of minutes, and that the gel strength vary within certain limits, low enough on the one hand to permit easy flow and high enough on the other to suspend cuttings and weighting material when quiescent. The gel strength is the minimum stress necessary just to start flow at any given time. Gel strength is therefore synonymous with yield point, which is related to the apparent viscosity or mobility in the sense that the mobility curve when extrapolated intersects the stress axis at the positive value that corresponds to the yield point.

The advantages and disadvantages of thixotropy in drilling muds have been discussed by many authors and summarized by Evans and Reid.[7] With the thought in mind that thixotropy is related to the rate at which gel structure is built up as well as to the absolute magnitude of the gel strength, it is apparent that the thixotropic properties of the mud must have an effect on the types of flow at various points within the rotary circulation system and hence are of direct concern in pumping problems; and together with the gel strength must have an important bearing on the rate of release of cuttings and entrained gas, on the retention of weighting material and cuttings in the hole during either forced or purposeful shutdown of the circulating pumps; in problems of lost circulation; in magnifying the mechanical problems when drilling heaving shale; and in running long strings of casing and Schlumberger cables; while the rate of structure formation is perhaps more important than absolute strength in the wall-building process and in the degree of penetration of permeable sands.

That most clay suspensions when undisturbed tend to develop considerable mechanical strength, presumably due to some sort of structural aggregation of the particles, and that they lose this mechanical strength immediately on chemical treatment, is shown by the curves of Fig. 3. In these experiments the suspension was confined in an annular space between an outer, stationary, cylinder and an inner one suspended by a torsion wire. The head of the torsion wire was rotated at a constant speed of only one revolution per hour and the shearing stress just necessary to move the rotor was taken as a measure of the mechanical strength, or gel strength. Similar data are reported by Garrison.[3]

After chemical treatment and in the absence of salt the apparent viscosity of a mud usually is found to be relatively independent of the shearing stress as shown by the curves of Fig. 4 for Frazier Mountain clay. Moreover, the relationship between viscosity and concentration for treated suspensions is in fact often described fairly

well by the Einstein equation $\eta/\eta_0 = 1 + 2.5\nu$ for spherical particles. These facts show that structural viscosity is destroyed by chemical treatment, and they also suggest that greater viscosity reduction than is obtainable with polyphosphates probably is not to be expected except perhaps for dialyzed clays.

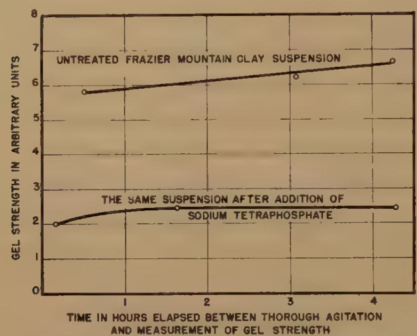


FIG. 3.—RELATION OF GEL STRENGTH TO TIME OF SETTING, AND EFFECT OF TETRAPHOSPHATE.

often by a distinct rebound when driving forces are removed. Chemical treatment destroys this elasticity, as shown by the inserted curves of Fig. 5: after addition of

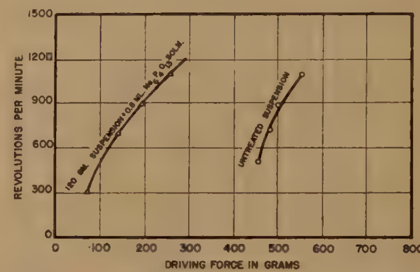


FIG. 4.—RELATIONS BETWEEN SHEARING STRESS AND RATE OF SHEAR FOR TREATED AND UNTREATED SUSPENSIONS OF FRAZIER MOUNTAIN CLAY. STÖRMER VISCOSIMETER.

sodium tetraphosphate there is no longer any observable initial increase in resistance to deformation with deformation, but instead the apparent viscosity drops rapidly to a low value. In untreated or salt-treated

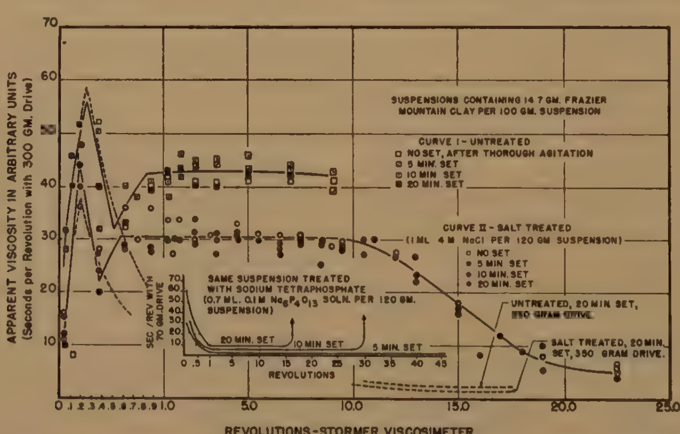


FIG. 5.—CHANGES IN APPARENT VISCOSITY WITH DEFORMATION FOR VARIOUSLY TREATED SUSPENSIONS.

Elasticity.—The gels of clay suspensions containing salt or to which viscosity-reducing chemicals have not been added are elastic. This is shown for such suspensions by a rapidly rising resistance to deformation as deformation increases, at the beginning of Störmer viscosity measurements, illustrated by the curves of Fig. 5, and also

suspensions, structural breakdown follows deformation beyond the initial elastic range. At the shearing stresses used, breakdown is followed by a secondary increase in resistance, suggesting secondary structural resistances: at higher shearing stresses the breakdown may be much more complete, as indicated by the dotted curves. The

lower apparent viscosity of the salt-treated suspensions at all stages of deformation and the marked drop in viscosity on continued deformation is in agreement with the pre-

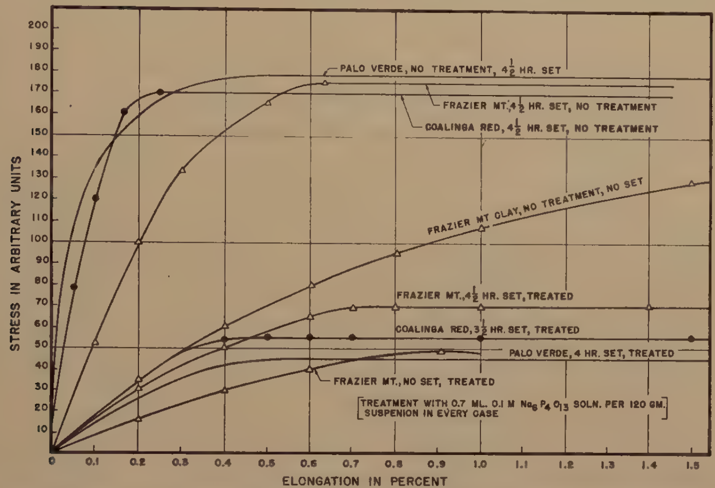


FIG. 6.—STRESS-STRAIN CURVES FOR CLAYS BEFORE AND AFTER CHEMICAL TREATMENT AND AFTER VARIOUS SETTING TIMES.

sumption that salt produces ionic forces between particles, a point to be developed in detail in this paper, since such forces should help to promote streamlining under the influence of the shearing motion. Chemicals such as sodium tetraphosphate destroy structure, but they are not used in amounts sufficient to produce marked ionic effects. Abrupt increases in resistance to deformation occur in time with untreated or treated suspensions, as illustrated by the inserted curves of Fig. 5 for treated suspensions at low shearing stresses. This is probably attributable to multiplication of particles, which tends to occur spontaneously but is accelerated by the shearing motion.

Gel Strength.—Gel strength was measured with a modified MacMichael type of instrument, as has been described. The curves of Fig. 6, in which results for three clays are summarized, were obtained with this instrument. At least for Frazier Mountain clay the gel strength increases with time of set whether or not the suspension has been chemically treated; at the same time the elastic elongation tends to decrease. This might be called stiffening and indicates a slow building up of colloidal structure. The structure that is built up is distinctly weaker for chemically treated suspensions. The tensile, mechanical, or gel strength is probably largely the result of edge to edge contact and is destroyed by chemical treatment, as will be discussed later in detail. The remaining gel strength measures the force necessary to move the particles out of potential troughs and the remaining elongation is a measure of the depth of such troughs. The tensile strength and power to stretch have entirely disappeared as a result of chemical treatment. This was shown also by the curves of Fig. 5.

Effect of Chemical Treatment on Rate of Gel Formation and on Gel Strength

Viscosity-reducing chemicals greatly reduce the viscosity and yield point, or gel strength of muds, but apparently do not significantly change the initial gelling rate of completely de-gelled muds. Although measurement of initial gelling rate is obviously subject to large experimental

errors, the data of Table 1 suggest that this property passes through a maximum with increasing salt concentration. These data certainly show distinct maxima in the absolute gel strengths with addition of sodium or calcium chlorides, whether or not viscosity-reducing chemicals are also present. Apparently viscosity reducers destroy only the portion of the absolute gel strength in any mud that is attributable to adhesion between particles, and the gel strength attributable to intermicellar forces arising from ionic clouds may at the same time be increased by adding salt. Thus while viscosity-reducing chemicals destroy both elasticity and gel strength an equivalent degree of gel strength, which may differ in its mechanism but not necessarily in its utility, may be regained in a treated mud by adding salt. The possibilities in simultaneous variations of salt and viscosity reducers do not appear to have been exploited.

Crystal Structure

Chemically, clays are hydrated aluminum silicates, most of which may be classified as either kaolins, $Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$, or montmorillonites, $Al_2O_3 \cdot 4SiO_2 \cdot H_2O$. These formulas represent ideal analyses of the acid or amphoteric clays. Both the kaolins and the montmorillonites (or bentonites) are composed of superimposed layers of aluminum and silicon bound together through oxygen bridges.[9] The structures of the kaolin and montmorillonite unit sheets have been given by Hofmann, Endell and Wilm[10] and reproduced by Reed.[11] Many of these unit sheets may be combined in individual clay particles. The possibility of water penetrating between the sheets in montmorillonite has been mentioned by Hauser and Reed[12] and theoretically it could cause their complete separation.[13]

That clay particles, like the unit sheets of which they are composed, are themselves plates can be directly observed in some cases, or inferred from streaming in polarized light, or from the nature of the twinkling in the ultramicroscope.

Nature of Forces Producing Structure in Clay Suspensions

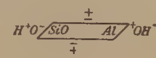
Various mechanisms have been advanced to explain the thixotropy of clays. Lewis, Squires and Thompson[14] emphasize the platelike character of the particles and suggest that overlapping will build up large and long agglomerates. A persistent objection to this idea is that gelation occurs in suspensions so dilute that contact is impossible,[12] but gelation at this dilution is observed only on the addition of salt; at higher concentrations at which gels are formed without salt, continuous contact between particles is possible. Salmang[15] has postulated immobilization in microscopically thick hulls of bound water, but calculations based on the sorption capacity for exchangeable ions[16] and on heats of sorption[17] lead to the conclusion that the thickness of the solvation mantle cannot exceed 25 to 40 Å., and Hauser and Reed[12] observe a marked decrease in the setting time of bentonite suspensions with temperature, which they regard as inconsistent with the bound-water theory as solvation is generally considered to decrease with temperature. Another view due to Freundlich[8] and Hamaker[18] is that the particles in thixotropic clay suspensions are held at equilibrium distances such that forces of repulsion due to interpenetration of the diffuse ionic clouds are just balanced by forces of attraction that are assumed to be the London-van der Waals forces.[8,18,19] Langmuir[20] substitutes for long range van der Waals forces the Coulomb attraction between the micelles and the oppositely charged ions in solution.

The theories of Freundlich, Hamaker, and Langmuir apply to uniformly charged particles, but variations of exchange capacity with SiO_2-R_2O_3 ratio,[21] orientation in an electric field[22] and the high electrical

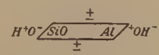
conductivity of masses deposited on the anode membrane in electrodialysis as opposed to the low conductivity of non-oriented thixotropic systems,[23] all suggest that positive as well as negative areas are to be found on clay particles. The crystal structures of clays[10] show that the planar and transverse surfaces of particles should differ radically. Since all transverse surfaces must be formed by breaking the lattice, they should expose both aluminum atoms with unsaturated valences or unsaturated aluminum-oxygen groups that normally react with water to form hydroxides, and unsaturated oxygen atoms attached to silicon that normally react with water to form silicic acid. Over the planar silica surfaces secondary valence forces will induce acid hydrolysis of adsorbed water, and over planar alumina surfaces (as are found in kaolin) the reverse may be expected. Thus, in the same particle, both positive and negative reactive areas, points or edges are available.

The electrostatically negative planar surfaces of clay will be balanced by clouds of H^+, Na^+ or other positive ions; the electrostatically positive planar surfaces will be balanced by clouds of negative ions. Between like surfaces, according to the analysis of Freundlich, Hamaker, and Langmuir, there is mutual attraction balanced by kinetic repulsion, so that very high equilibrium distances of separation are possible. However, between different kinds of broken bonds on the transverse surfaces or at the edges or corners of the particles, or between edges and planar surfaces of the opposite charge, or between dissimilar planar surfaces actual contact which may be regarded as chemical reaction should be expected. Structures in untreated clay suspensions are attributable, then, to the combined effects of attraction between dissimilar surface edges or corners, and to repulsion or large equilibrium distances of separation which occur primarily between like planar surfaces.

The clay particle may be considered a colloid-molecule, and symbolized by the formulas:
for montmorillonite (bentonite):

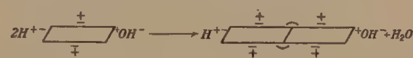


or for kaolin:



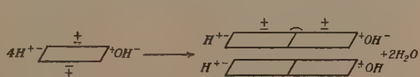
Kaolin and Bentonite

In suspensions of hydrogen bentonite elimination of water between particles may occur as indicated by the equation



Since the particles are never of regular shape, less ideal configurations result, which permit structures in three dimensions. In hydrogen bentonite, however, the planar ionic clouds are so feeble that there is little or no mutual repulsion, and consequently there is no thixotropic structure. The equilibrium distance between particles is so small that dense aggregates are formed. Experimentally it is found that well dialyzed bentonites swell only to a limited extent in water.[24] Similarly, some clays low in alkaline salts, such as are found in wet climates, will not form thixotropic suspensions unless small amounts of electrolytes are added. These electrolytes presumably effect replacement of hydrogen ions by metallic ions, with a resulting increase in the concentration of the interplanar ionic clouds, so that a certain amount of mutual repulsion between particles is obtained.

For kaolin the condensation between the edges of particles should be analogous to that for bentonite, but the structures formed should tend to be more compact because of the dissimilar nature of the faces:



The resultant differences in the average particle size of these clays as found may be enormous, as can be observed microscopically or inferred from wide differences in settling rates. These differences in particle size are sufficient to account for the wide differences between the properties of suspensions of kaolin and bentonite.

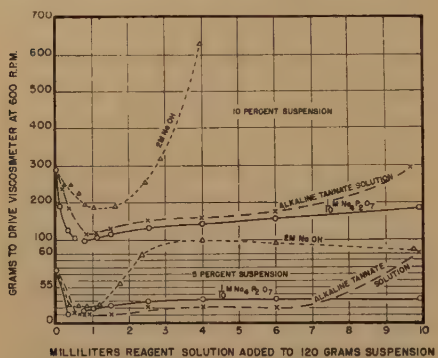


FIG. 7.—AMOUNTS OF VISCOSITY-REDUCING CHEMICALS REQUIRED AT DIFFERENT CONCENTRATIONS OF CLAY.

PLATING ACTION OF VISCOSITY-REDUCING CHEMICALS

Experiments have been described which indicate that viscosity reduction by small amounts of large negative ions is a surface effect. Presumably these ions react with the exposed aluminum atoms on the broken transverse surfaces. Considering only bentonite and representing the viscosity-reducing chemical by Naθ, the reaction can be symbolized thus:

$$H^+ \text{—} OH^- + 2Na_x\theta \rightarrow 2H^+ \text{—} \theta^- Na^+_{x-1} + NaOH$$

The contact structure has been destroyed and unipolar particles produced.

GELLING ACTION OF SALTS

The amounts of specific viscosity-reducing chemicals required for maximum effect with Frazier Mountain clay are proportional to the amounts of clay, but the amounts of salt required to produce gelation are proportional to the amounts of water (Figs. 7 and 8). They are in agreement with the ideas that viscosity-reducing chemicals plate certain surfaces of clay particles and that salts affect the ionic atmospheres between the planar surfaces, or between all surfaces, first increasing and then decreasing the effective ionic attraction.

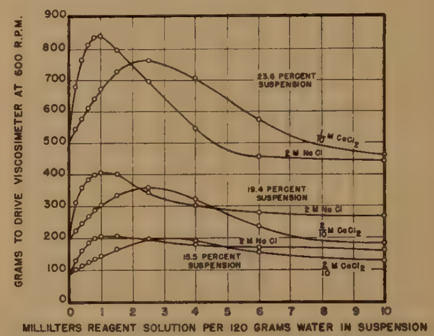


FIG. 8.—AMOUNTS OF SALT REQUIRED FOR GELATION AT DIFFERENT CONCENTRATIONS OF CLAY.

At low or moderate concentrations salts raise the yield point of a suspension, and presumably this is because the forces required to move the particles out of their oriented positions increase; for the same reason they raise the apparent viscosity; and they tend to raise the initial gelling rate, as measured by the increase in yield point with time, because the increased forces between the particles raise the speed with which they seek their equilibrium positions. At higher concentrations of salts, at which the ionic atmospheres tend to be suppressed, these effects are reversed: the yield point, the apparent viscosity, the initial gelling rate, and the final gel strength being all progressively lowered, so that these properties tend to go through a maximum with increasing salt concentration. Viscosity-reducing chemicals, on the other hand, are added in small amounts and perform the single function of preventing adhesion between particles. They do not appreciably affect the ionic atmospheres and consequently the initial gelling rate is

not changed by their use. They greatly reduce the gel strength and viscosity attributable to structural contact between particles but, as has been shown by Table 1 these effects can be nullified and reduced progressively to zero by adding salt.

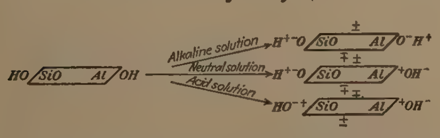
TABLE 1.—*Effects of Viscosity-reducing Chemicals and Salts on the Gel Strengths and Initial Gelling Rates of Clay Suspensions*

Properties	1 No Treatment	2 +½ ml. 4M NaCl	3 +2 ml. 4M NaCl	4 No Treatment	5 +½ ml. $\frac{1}{10}$M $Na_4P_2O_7$	6 Same as No. 5 +½ ml. 4M NaCl	7 Same as No. 6 +1 ml. 4M NaCl	8 Same as No. 7 +2 ml. 4M NaCl	9 Same as No. 8 +4 ml. 4M NaCl	10 Same as No. 9 +6 ml. 4M NaCl	11 No Treatment	12 +1 ml. $\frac{1}{10}$M $Na_4P_2O_7$	13 Same as No. 12 +1 ml. $\frac{3}{10}$M $CaCl_2$	14 Same as No. 13 +2 ml. $\frac{3}{10}$M $CaCl_2$	15 Same as No. 14 +4 ml. $\frac{3}{10}$M $CaCl_2$
Equilibrium viscosity	210	395	260	176	82	137	180	246	208	185	165	70	79	92	153
Initial yield point	160	320	190	130	15	85	125	180	150	120	105	5	14	29	71
Yield point after 5 min	185	320	190	140	32	105	145	200	175	140	118	13	22	48	105
Yield point after 10 min	190	320	200	154	28	130	150	205	180	140	120	20	29	54	200
Initial gelling rate	15			10	15	20	20	20	25	20	13	8	8	19	34

The data for Table 1 were determined with the Störmer viscosimeter. The load just necessary to start rotation was taken as the yield point, and the increase in yield point in the first five minutes after thorough stirring is taken as a measure of the initial gelling rate. In similar experiments it has been noted that the effects of adding combinations of calcium chloride and sodium pyrophosphate are not greatly affected by the order of addition, showing that the reaction is not primarily one between calcium and pyrophosphate ions in solution.

EFFECTS OF ALKALIES

For the montmorillonite particle the possible reactions of hydrolysis are:



In accordance with these formulas two minima in viscosity or yield-point curves are observed with increasing pH.[25,14]

On adding sodium hydroxide to a neutral suspension, the first effect is to induce the acidic hydrolysis of alumina and then to affect the ionic clouds in the same way as salts. This dual action is well illustrated by the curves of Fig. 7. Since the effect of sodium hydroxide in inducing acidic hydrolysis of alumina is a mass-action effect, the viscosity reduction obtained is comparatively low because gelation is simultaneously produced.

The sodium silicates, $Na_2O{\cdot}3.3SiO_2$, $Na_2O{\cdot}2SiO_2$, and $Na_2O{\cdot}SiO_2$, are decreasingly effective as viscosity reducers in the order listed, probably because the series represents transition from the plating effect of a large negative ion or colloidal micelle to the mass-action effect of sodium hydroxide. Similar results with silicates are obtained in treating pottery slips.

BOUND WATER

Hauser and LeBeau[26] have reported apparent densities of bentonite in water, which increase with concentration and with decreasing particle size, and they conclude that these changes represent adsorption of water in progressively thicker hulls. These facts suggest, however, that no water is bound to single particles, especially since at low concentrations apparent

densities are found which are equal to, or even less than, the dry density of bentonite. An alternative conclusion is that water is compressed between particles rather than on them, or in aggregates, so that the observed increased apparent density may be attributed to the primary valence forces or to the interplanar attractive forces that tend to draw the particles together. It is, therefore, not necessary to assume that the attractive forces arise from the bound water. Houwink[27] points out that compressed water films need not impart rigidity, as Salmang[15] assumes, in view of van Laar's observation that the viscosity of such films between glass plates does not necessarily deviate from that of water in its ordinary state.

Geometric Calculations

Reference has been made to the fact that gelation is observed in bentonite suspensions so dilute that contact is impossible. Hauser and Reed[12] report traces of structure at concentrations as low as 0.05 per cent and they calculate that at 0.1 per cent the theory of Lewis, Squires and Thompson[14] must assume ratios of length and breadth to thickness of the individual particles of the order of 1000–2000: 1. The particles used had an average equivalent spherical diameter of 180 Å., and for such particles the highest possible ratio of length and breadth to thickness is 58: 1 if the thickness is that of a unit sheet, or 9.2 Å. Continuous contact is thus impossible; consequently Hauser and Reed observe structure at this dilution only in the presence of a strong electrolyte such as potassium chloride.

In the absence of added salt the lowest concentrations at which gelation has been observed are 1.4 per cent for particles having an average equivalent spherical diameter of 140 Å.[12] and 1.5 per cent for particles having an average equivalent spherical diameter of 300 Å.[20] At these concentrations ratios of length and breadth to thickness of 58: 1 will permit edge to edge contact to form loose structures. Thus the lowest concentration at which structure is obtained, unless by salt gelation, agrees satisfactorily with that permitted by the geometry of the system.

Summary and Conclusions

The outstanding problems in the further development of rotary drilling fluids are considered in the light of the colloid chemistry of clay suspensions as we know it today.

Mechanisms of the effect of various chemicals now in general use to control the rheological properties of drilling muds are proposed with the hope that they may point the way to the successful solution of some of these unsolved drilling problems.

It is shown that viscosity-reducing chemicals are adsorbed on specific surfaces of the clay particles and that they reduce the viscosity of suspensions by destroying the portion of the absolute gel strength that is attributable to adhesion between particles. On the other hand, salts are not adsorbed but cause gelation and coagulation because of induced changes in the interparticle ionic atmospheres.

Results of a comparison of the viscosity-reducing effects of the polyphosphates with other standard viscosity reducers show that sodium pyrophosphate is one of the most effective. However, it is found that among the polyphosphates the pyrophosphate, which has the lowest molecular weight, produces the least permanent effect and that as the molecular weight increases to the decaphosphate there is a corresponding increase in the permanence of the viscosity lowering. This behavior suggests diffusion into inner particle surfaces, the rate of which decreases as the size of the adsorbed molecules is increased.

Proof is given that the tannate and pyrophosphate ions are adsorbed on the

same surfaces of the clay particles and that the polyphosphates produce equal viscosity-lowering effects per molecule because they cover equal areas per molecule.

The application of thixotropy and gel strength to drilling problems is discussed in detail and it is shown that while both elasticity and mechanical strength of clay gels are destroyed as a result of chemical treatment, the initial gelling rate of muds in the completely de-gelled condition is not significantly changed. An equivalent degree of gel strength, which may differ in its mechanism but not in its utility, may be regained in a treated mud by adding salt.

On the basis of the detailed structure of clays as revealed by X-ray analysis, chemical formulas are written for colloidal clay particles and utilized to explain most of the phenomena shown by clay suspensions. Finally, it is shown that the assumption of edge to edge contact to form structures in clay colloidal systems is in accordance with the experimental facts.

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DISCUSSION

By G. H. Fancher,* Austin, Texas.—Dr. Loomis' work should prove particularly helpful to those who are confronted with similar problems on the Gulf Coast.

Dr. Loomis has provided a theory of the mechanism of chemical treatment of drilling fluids through the applications of principles of colloidal chemistry. The theory is confirmed by experimental evidence. As one consequence, the initial effects of many chemicals must be ascribed to adsorption or a loose chemical combination at the surfaces of the colloidal micelle. These particular results were confirmed experimentally through the use of phosphates. Secondary effects evidenced by increase in viscosity were thought to be due to migration of adsorbed ions into the lattice of the colloidal micelle.

This is particularly interesting to us because Gulf Coast mud engineers are familiar with the fact that chemically treated muds frequently revert and behave as only partly and incompletely treated muds. Additional evidence would seem to be necessary to confirm this, because a possible explanation could be a reduction in particle size occurring after treatment. An increase in surface would result with the resulting increase in viscosity and attendant effects. Dr. Loomis' data regarding the relation of particle size and other factors are particularly interesting but would be more significant if the particle size had been determined after chemical treatment and eventual rise in viscosity as well as before chemical treatment.

The problem of the transitory nature of the effects obtainable by chemical treatment of drilling fluids is exceedingly important in the field and an adequate explanation of mechanism resulting in a remedy would be welcome and practical. Considering again Dr. Loomis' data regarding this effect, there is another possible explanation. The chemicals used were complex phosphates in various stages of dehydration. The more complex and nearly dehydrated products were shown to be more effective. Since these products are easily made in the laboratory by partial dehydration, would it not be possible for these products to revert to simpler form after adsorption on the colloidal

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particle by addition of water? Is information available regarding the stability of these compounds, rate of reaction and the equilibria involved?

Other problems encountered in the field are overtreatment of mud and the treatment of cement-cut mud with bicarbonates. Concerning both, perhaps the mechanism of chemical treatment proposed by Dr. Loomis can be extended to provide a satisfactory explanation. It would seem clear that in either case, however, the effects must be more ionic in nature than concerned with adsorption.

Overtreatment of mud and deterioration of chemically treated muds regardless of mechanism (although here Dr. Loomis' mechanism is particularly significant) emphasize the necessity in the field for careful use of chemicals. Exactly the amount required to obtain the desired effect (usually the maximum possible) as regards viscosity reduction, no more and no less, should be used in all cases. Field practice could be improved considerably in this respect with greater satisfaction and significant reduction in costs resulting.

While in general we can agree that the effect of the various dehydrated phosphates is as presented, perhaps the nature of the mud has something to do with the effect. Gulf Coast mud engineers are all familiar with the fact that pyrophosphates, for example, may be effective in treating a given mud for reduction of viscosity and quite ineffective with another mud. Also, we know of situations in the field in which acid phosphate proved to be more effective for reduction of viscosity than pyrophosphate, which, as I understand Dr. Loomis, is contrary to the theory postulated. So perhaps the nature of the mud may be as significant as the type of chemical used.

For the past two years a research program in drilling fluids has been followed in the Petroleum Engineering Department of The University of Texas. We can confirm from our own investigations the results reported by Dr. Loomis regarding the effects of time of setting, the development of structure and gel strength. In this connection, we should not lose sight of the fact that most Gulf Coast muds possess more than adequate gel strength. Gel strength of mud should be sufficient only to prevent the setting of cuttings, and of course, weighting materials, if these are used. Settling can occur to an appreciable extent only when adequate circulation is interrupted. Furthermore, settling of cuttings is serious only when the drill pipe is in the hole at such times or when a survey or test is being made. Less gel strength is required at greater rates of circulation and at lower rates of penetration. Excessive gel strength may cause more trouble than good.

Interesting questions arise suggesting at least some additional research. Of these I consider the most important one to be: What is the ultimate effect of a deflocculating agent? Understanding of the mechanism involved should speed the answer.

A. G. Loomis (author's reply).—Dr. Fancher has raised some very interesting and practical questions and we shall try to show that the present theory adequately answers most of them. We agree *a priori* that more work is necessary; in fact, a satisfactory theory should suggest new experiments and point out the phases of the general subject that should be most fruitful for investigation to explain unsolved problems.

Referring to Dr. Fancher's discussion of the reversion of viscosity in chemically treated muds, we assume that chemical treatment shifts the equilibrium

$$(\text{clay particles})_n \rightleftharpoons n\ (\text{clay particles})$$

to the right and keeps it there by virtue of the imposed negative charge; that is, by producing unipolar particles. The treating chemical does this by attaching itself to the surfaces for which it has specific affinities or attractions. In our paper we suggest that reversion of viscosity on aging may be due to diffusion (or migration) of treating agent into the lattice of the particle. In this manner some of the "plated" outside surfaces would become uncovered and so again capable of attaching themselves to other surfaces, as they were attached before treatment. This diffusion of ions into inner particle surfaces might be expected to promote splitting of particles along the cleavage planes between crystal sheets, perhaps with complete separation of sheets. Thus, as Dr. Fancher suggests, and as we also point out on page 88, a reduction in the average particle size might be a secondary effect of the loss of treating agent.

In the ideal case by this process the individual particles would be reduced in thickness but not in area. For the sum of the particles

there would be no change in the total area of transverse surface (across the crystal lattice), but a large change in the total area of planar surfaces, and a large change in the total length of edges. If the amount of chemical required for reduction of viscosity were found to be inversely proportional to the average particle size when particle size was reduced by interlaminar cleavage alone, it could be concluded that the chemical is adsorbed on the planar surfaces, or edges, or perhaps on planar surfaces and edges; on the other hand, if such a proportionality were not found, the conclusions would be that the chemical is adsorbed on the transverse surfaces. We are now checking this point in the laboratory by rheological and centrifugal measurements on treated and untreated bentonite of graded particle sizes.

Dr. Fancher suggests that the transitory nature of the effects obtainable with the polyphosphates may be due to degradation of the chemicals after adsorption. Presumably he refers to the theoretical possibility of converting any of these compounds to orthophosphates by adding water. However, the polyphosphate that is most transitory in its effects, pyrophosphate, is also the most stable in water solution. Mellor[28] states that alkali pyrophosphates are unchanged either by standing a long time or by boiling in water. The tetraphosphate, $Na_6P_4O_{13}$, on the other hand, is slowly transformed into orthophosphate (Mellor, *ibid.*, 991). Nevertheless, the viscosity-reducing effect of tetraphosphate is more permanent than the effect of the more stable pyrophosphate.

Evidence that the compounds do not revert rapidly in water to their original components is that the compounds are less effective as viscosity reducers, on a weight basis, than mixtures of the components, such as pyrophosphates and hexametaphosphates, which may have been fused together in their preparation (cf. p. 89). Degradation of the polyphosphates to simple forms, therefore, does not seem to us to be a major factor in explaining the transitory nature of the effects noted.

As Dr. Fancher suggests, the mechanism proposed adequately explains overtreatment, which is purely an ionic effect, and entirely analogous to the effect of adding salts to the mud, as suggested on page 95. In cement-cut mud, in addition to the ionic effect, there would be a competition between Ca^{++} and the clay particle for the phosphate or tannate ion, hence such mud would treat only partially and the Ca^{++} should be initially removed with $CO_3^{=}$.

It is pointed out that the nature of the mud has something to do with effective treating. We quite agree and have recognized this point in giving data for three different clays in Fig. 6, and the fact is implicit in our discussion of the effects of salts. In line with this, we do not agree that the occasional greater effectiveness of acid phosphate over pyrophosphate for some muds is contrary to the theory, for such phenomena appear to be essentially ionic. In muds that are too alkaline, the chemical treating agent cannot add to the particles at all, since the hydrolysis over alumina surface is suppressed, and so the specific effect of the treating agent is lost. In such cases the viscosity would be relatively high and would remain high on treatment with a polyphosphate. Acid phosphate, however, should neutralize the alkalinity and precipitate calcium ion, thus eliminating the gelling effects of excess alkali and of bivalent calcium ion, with a consequent lowering of the viscosity. Following this treatment, pyrophosphate would be expected to further lower the viscosity.

[28] Mellor: Treatise on Inorganic and Theoretical Chemistry, 8, 975.

A Preliminary Report on the Application of the Mass Spectrometer to Problems in the Petroleum Industry

By Herbert Hoover, Jr.,* Member A.I.M.E., and Harold Washburn†

(New York Meeting, February 1940)

This paper is in the nature of a rough preliminary report on the progress that has been made in the application of the mass spectrometer to various problems arising in the petroleum industry. A few years ago the authors considered a number of the problems that were arising in the qualitative and quantitative measurement of small amounts of hydrocarbons. The methods available of making analyses by chemical techniques appeared to leave much room for improvement. Without going into the reasons at this point, attention was turned to the possibility of employing physical instead of chemical methods of accomplishing the desired results.

A preliminary investigation disclosed that the mass spectrometer presented a possibility of solving many problems which could not easily be accomplished by other methods. Work was begun in developing the necessary apparatus and technique. A great deal of encouragement and many valuable suggestions were received from Dr. Robert A. Millikan, Dr. W. R. Smythe, and Dr. W. N. Lacey, of the California Institute of Technology, and from Dr. E. O. Lawrence, who recently received the Nobel Prize, of the University of California. The authors particularly wish to acknowledge the very great willingness of these outstanding scientists to be helpful in solving many of the problems that were involved.

So far as the authors are aware, this was the first application of the mass spectrometer to commercial work. The results were considerably better than had at first been anticipated. Briefly, it is possible to run a qualitative and quantitative analysis of an unknown mixture of hydrocarbon gases, with an accuracy of better than plus or minus 5 per cent of each of the various constituents. An exceedingly high degree of sensitivity has been obtained, and a relatively short time is required to complete an analysis. Furthermore, it is unnecessary to separate a mixture of gases into its various components in order to complete the analysis.

The Mass Spectrometer

The mass spectrometer should not be confused in any way with the optical or grating type of spectrograph now in general use. The operation of the mass spectrometer is entirely different in principle and bears practically no resemblance to the optical or grating instruments.

The original conception and development of the mass spectrometer dates from and is generally credited to Aston, of Cambridge, England. An early accomplishment of his research, about 20 years ago, was the discovery that the inert gas neon was actually a mixture of two kinds of atoms, one of the atomic weight 20 and the other of atomic weight 22. These two components occurred mixed in such proportion as to yield the usual atomic weight of 20.2.

The study was continued and most of the elements were shown to be mixtures of components whose atomic weights can, to

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a close approximation, be expressed as whole numbers. These components that form an element are known as isotopes. The research also showed that the masses of the isotopes differed slightly from whole numbers. This difference is due to the way in which the neutrons and protons are bound, and when expressed as a fraction of the atomic weight is called the "packing fraction." The mass spectrometer was able to determine these packing fractions.

The mass spectrometer has also been used in the study of ionization potentials of pure gases, such as ethane. Other studies have aided in the determination of the ages of rocks by measuring the presence of a lead isotope that occurs in a pure form as a result of the disintegration of uranium. Because of the complexity of the apparatus, and the purely scientific aspects of the results, the work was confined for the most part to educational and pure science institutions.

As a result of the work to be described here, however, the mass spectrometer technique has been extended, and now it finds a new and practical use in the chemical analysis of unknown gas and vapor mixtures. The previous work had been confined almost entirely to the study of the molecular structure and physical behavior of known gases. Relatively pure samples of known gas had been used and so far as the authors are aware there has been no prior attempt to make quantitative measurements of the amounts of two or more unknown gases in a mixture.

Several types of mass spectrometers have been developed, each type being adapted to certain special uses. For simplicity, only one type will be described here.

This spectrometer is shown diagrammatically in Fig. 1. It consists of the ionization chamber *a*, the analyzer tube *b*, the collector *c*, and the amplifier *d*. The ionization chamber, analyzer tube and collector are enclosed in an air-tight container, which is kept under a high vacuum. This container is placed in a uniform magnetic field, preferably supplied by a large electromagnet. The gas to be analyzed is introduced into the ionization chamber through a capillary leak or gas inlet.

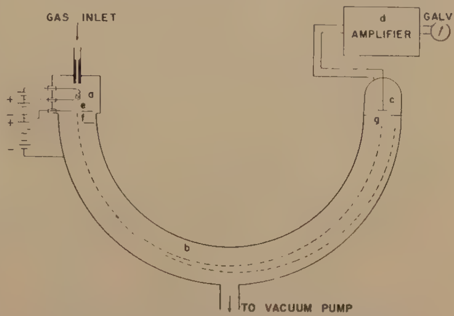

FIG. 1.—DIAGRAM OF SPECTROMETER. Magnetic field perpendicular to plane of paper.

In the ionization chamber, the gases are bombarded by low-voltage electrons emitted by a filament. This bombardment ionizes the molecules and thereby they become positive ions. As a result of their positive charge the ions are accelerated toward the slit *e*, which is kept at a small negative potential with respect to the rest of the ionization chamber. After passing through *e*, the ions are further accelerated toward slit *f*, which is kept at a large negative potential with respect to slit *e*. This potential is usually of the order of a thousand or more volts. The ions thus pass through slit *f* at a high velocity. The path they take, however, is not straight, but curved, owing to the action of the magnetic field. The radius of curvature of the path for a given accelerating voltage depends upon the ratio of the charge on the ion to its mass or atomic weight. Hence the ions of a given mass or atomic weight will follow one curved path while those of a heavier mass or atomic weight will follow another curved path of greater radius. By proper adjustment either of the magnetic field or of the accelerating voltage, or of both, ions of any desired mass can be made to follow a predetermined radius of curvature and thus to pass through the exit slit *g*.

Only the ions passing through this slit can strike the collector c, where their quantity is measured by a suitable vacuum-tube amplifier and galvanometer or recorder.

Spectrometer Measurements

Thus the quantity of ions present of any particular mass can be measured by properly adjusting the magnetic or electric fields of the spectrometer and measuring the deflection on the galvanometer. To complete the analysis it is then necessary to determine the relation between these spectrometer measurements and the amount of gases or vapors present in the mixture being analyzed. The method of making this final step has been developed in our laboratory, and a general description is given here.

Experiment shows that if the ionizing voltage is raised above a certain critical point, each gas or vapor can be made to produce ions of several different masses. The number of ions of each mass produced depends on the type and quantity of gas or vapor and on the voltage of the ionizing electrons. In other words, each gas or vapor has an ionization or cracking pattern, which is a function of the ionization voltage. From a knowledge of these cracking patterns and their variation with ionization voltage, together with a knowledge of isotope ratios and packing fractions of the ions recorded, the quantities of the various gases and vapors present in the unknown sample can be determined. However, it is usually unnecessary to take all these factors into account in an analysis.

We have made a large number of analyses with the mass spectrometer and have found that for certain problems it possesses many advantages, some of which are outlined below. First, it is an instrument of exceedingly high sensitivity. A sample of gas as small as one-tenth of a cubic millimeter at atmospheric pressure and room temperature can be measured. This is smaller in volume than the head of an ordinary pin. If this gas, for example, were ethane obtained from a pint of soil, the quantity would correspond to only about 0.2 of one part per billion by weight. The sensitivity can be increased tenfold or one hundredfold if desirable, without undue complications.

Second, and more important, the mass spectrometer distinguishes with relative ease between similar hydrocarbons in a mixture, even though the sample is extremely small. It distinguishes, for example, between ethane (C_2H_6) and methane (CH_4), or between ethane (C_2H_6) and ethylene (C_2H_4) even though the methane or ethylene is 20,000 times as abundant as the ethane. This feature is very important in soil gas analysis for petroleum-prospecting purposes. In a small sample containing ethane, propane, and butane in addition to carbon dioxide, nitrogen, oxygen and water vapor, the amounts of ethane, propane and butane in the sample can be readily determined. This ability to analyze for gases mixed with other gases greatly simplifies the chemical process necessary in preparing the sample.

The quantitative analysis of mixtures of gases that are still more similar, such as normal butane and isobutane, can be made just as readily. This resolving power is remarkable when it is considered that these gases are isomers, having the same number of carbon and hydrogen atoms per molecule. The only difference between these gases lies in the internal arrangement of the atoms within the molecule.

In Fig. 2 are shown the separate cracking patterns for n-butane and isobutane. Equal quantities of the two gases were used in order to make the patterns comparable with each other, and the same ionizing potential was used in both instances. Each of these gases cracks in a characteristic way when bombarded by electrons under predetermined conditions.

The carbon-hydrogen content of some of the components produced by cracking, together with the relative masses of such

components, are shown on the horizontal scales of the spectra of Fig. 2. Vertical heights of the areas above the respective components represent the relative amounts of such components present in the respective mass spectra. The vertical scale is an arbitrary one.

Fig. 2 reveals that the mass spectra of n-butane and isobutane are sufficiently different to make it possible to distinguish

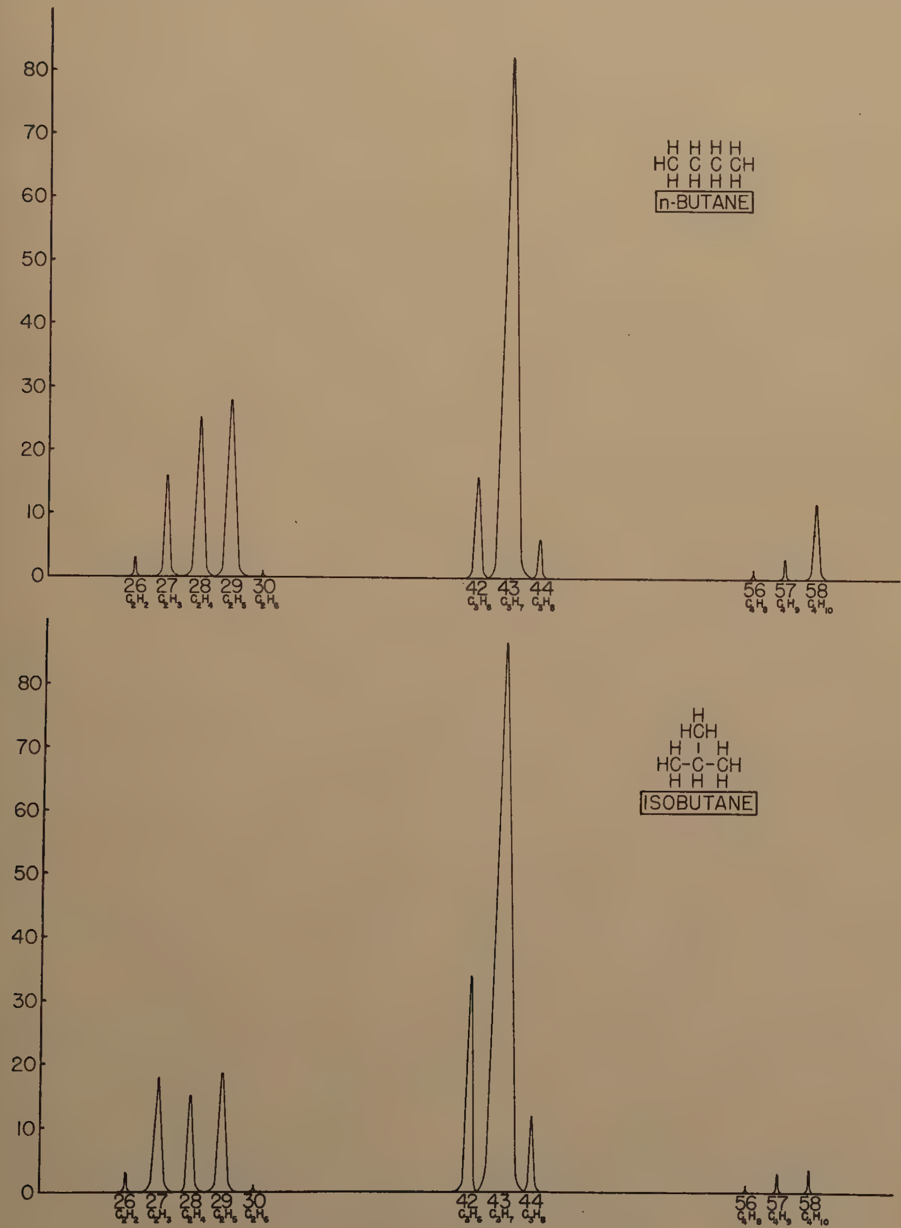

FIG. 2.—BUTANE CRACKING PATTERNS.

either of the gases from the other by inspection of the mass spectrum of the gas in question. When a mixture of these two gases is analyzed by a mass spectrometer the concentrations of each may be determined from the mass spectrum of the mixture.

The technique by which a quantitative analysis is made of a mixture of these two gases involves in this case the solution of two simultaneous equations based on the heights of the observed peaks and their ratios to each other. In actual practice the results may be obtained by direct methods, without having to go through the detailed calculations each time. A rapid qualitative and quantitative analysis of these or similar gases may be applied with considerable value in refinery operation and control.

Accurate and detailed physical analyses such as those outlined above can be made with considerable rapidity. Instead of a galvanometer indicating the quantity of ions of any one type, an automatic recording device may be used, which will give a record of the intensity of the ion beams of all mass units from, say, one to two hundred. Such a record may be produced in a few minutes. The actual recording can be done in approximately 5 min., while the pump-down time to clean up the apparatus requires an additional 5 to 10 min., before the next sample can be run.

The time necessary for analysis of a record depends on the number of constituents whose quantities are to be determined. When the quantities of three or four gases only are to be determined, we have found that less than five minutes is required for computation. In Fig. 3 is shown the pattern obtained from a mixture of equal parts of ethane, propane and n-butane. An experienced technician can tell at a glance approximately the quantities of gases in the samples. The computation can also be made automatically or semi-automatically if desired.

A spectrometer with several exit slits, each slit so placed that it passes only the ions of a single mass, has many practical advantages. With such a spectrometer the intensities of several ions having different masses can be simultaneously and continuously indicated and recorded. With such an instrument, a continuous record of certain constituents of a variable gas mixture can be obtained. This type of analysis is useful in refinery control. The output of such a spectrometer may be made to control automatically the process being monitored, according to the chemical composition of the output. Automatic control of recycling operations is only one of many possible applications.

The mass spectrometer now in use for general and analytical work is not adapted to portable operation because of its size and weight, and the nature of the accessory equipment that must be used with it. It is a relatively complicated and expensive piece of apparatus, and requires highly trained and technically competent personnel to achieve reliable results. The development and design of a suitable instrument is not a matter to be undertaken lightly. For instance, the vacuum pumps must be capable of continuously keeping the pressure at 10^{-6} mm. Hg or below, and gauges must be provided for accurately measuring these pressures. In order to obtain satisfactory resolution up to mass 200, the magnet structure and associated power supplies weigh several tons. The voltages of the power supplies must be held constant to within a fraction of one per cent. The amplifying and recording system must have a sensitivity of approximately 10^{-15} amperes if the full capabilities of the system are to be realized.

It is possible to design equipment to meet specialized problems, such as those presented in refinery practice, which would be semiportable and considerably simpler in operation. These advantages would be

gained, however, at the expense of sensitivity, and resolution at high mass numbers.

Although not the subject of this paper, some extremely interesting and significant observations have been made upon the distribution and quantities of various hydrocarbon and other gases in soil samples, drilling-mud samples, and borehole cores. A routine technique has been developed for qualitative and quantitative determination of the paraffin series, including methane, ethane, propane, butane, pentane, and still heavier members, together with some of their isomers.

It has been the purpose of the authors in presenting this paper to outline briefly an analytical technique by which very small quantities of hydrocarbon gases can be measured. No discussion of the geological significance of this work has been included. This aspect of the work is being carried forward actively on a purely experimental basis and will be reported upon later.

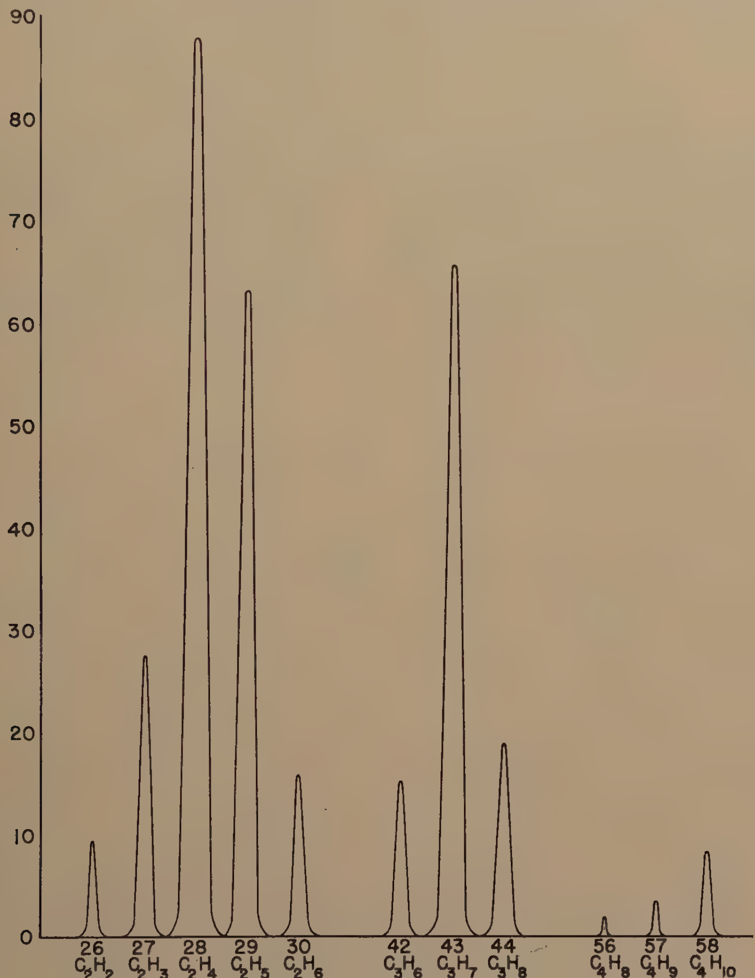

Fig. 3.—Cracking patterns.
3 cu. mm. ethane, 3 cu. mm. propane, 3 cu. mm. n-butane.

Acknowledgment

In conclusion, the authors wish to express their appreciation to the laboratory staff, whose work has helped make possible the practical solution of the problems outlined above.

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Steady Flow of Gas-oil-water Mixtures through Unconsolidated Sands

By M. C. Leverett* and W. B. Lewis*

(New York Meeting, February 1940)

The dynamic behavior of a multiple fluid system is completely describable in terms of driving forces and resistances to flow. The latter are proportional to the viscosity of the fluid under consideration and inversely proportional to a property of the system termed the "effective permeability" to that fluid, a property therefore defined by this relation.

Since three phases are usually present in oil reservoirs, it is essential to know the effective permeabilities to the several fluid phases, and the relationship between the composition of the fluid in the pore space and that of the flowing stream, in order to handle satisfactorily certain problems of oil production. In this regard, there are many unknown factors and parameters, and many that can be evaluated only indirectly. However, it is expected that work along lines similar to this present undertaking will help materially in solving these problems.

Previous workers in this field have investigated the two-phase systems, water-gas,[1] water-oil[2] in unconsolidated sands, and water-gas[3] in consolidated sands. The extension of the study of the flow of heterogeneous fluid systems from two to three phases involved only slight changes in technique. The apparatus used in the present work, except for slight changes to be described, was that used by Leverett in his water-oil experiments.[2] Correlation and interpretation of data were made by methods analogous to those used in two-phase work. The relative permeability to a phase—the effective permeability divided by the permeability of the system to a homogeneous fluid—was employed throughout in correlating the rate of flow of that phase with the composition of the pore space.

Quantitative measurements of two independent physical properties of the system were required to determine the composition of the pore space. As in the two-phase work, the fraction of water was determined electrically. The gas fraction was determined by measuring changes in volume accompanying measured pressure changes. Suitable account was taken of the solubility of the gas in the liquid phases, and of the vapor pressure of the water phase. Since this work was exploratory in nature, no attempt was made to obtain highly accurate numerical results. Reasonable precision and reproducibility were sought.

Experimental Procedure

Variables Considered.—Of the properties of the fluids, the oil viscosity is most likely in practice to vary widely. Variations in oil viscosity were therefore included in this work, but variations in other properties of the fluids are as yet unexplored. It appears unlikely that the normally encountered variations will produce significant changes. The observations were made at fairly high pressure gradients, no attempt being made to detect a variation of the relative permeabilities with pressure gradient. It should be pointed out also that since most of the data were taken on one sand size only, it can only be assumed at present that changes in

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[1] References are at the end of the paper.

sand size would produce no fundamental change in the correlation. This has been found substantially true for two-phase flow in unconsolidated sands, although Botset[3] has shown that consolidated sands exhibit properties considerably different from those of unconsolidated sands. The differences are quantitative rather than qualitative, however, so that the conclusions drawn from the present work are probably qualitatively applicable to consolidated sands.

Apparatus.—The heart of the apparatus consisted of a catalin cell described in Leverett's paper.[2] This held the tightly packed sand and was equipped with two perforated rings for pressure measurements and five additional, equally spaced ring-electrodes for resistivity measurements. The cell was connected to various appurtenances, which served either to supply fluid to the cell or measure fluid from it, or to measure quantities relating to the physical state existing in the cell. The nature and function of these are apparent from Fig. 1. Attention might be called to the liquid reservoirs, made by setting ordinary 5-gal. bottles in cement in gasoline drums. These proved satisfactory at pressures below 50 lb. and furnished relatively inexpensive "glass-lined" containers.

By joining a static manometer to the differential manometer, both the pressure in the cell and the pressure drop across the cell were measured.

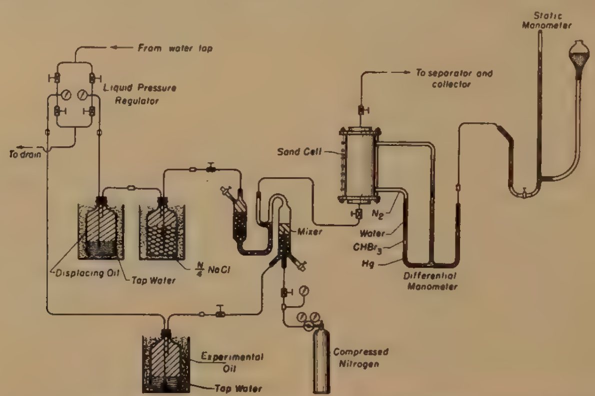

FIG. 1.—DIAGRAM OF APPARATUS FOR THREE-PHASE FLOW STUDY.

The effluent fluids went through a separator that permitted collection of the liquid phases in a graduated container. The gas was passed through a wet test meter or collected in a eudiometer, depending on the flow rate.

Experimental Methods.—Since the conductometric method of determining the water content of the experimental sand system has been described adequately,[1,2] the details will be omitted. Experiments showed that the presence of a third phase produced no deviation from the resistance-saturation relation established in two-phase studies.

The amount of gas in the cell was determined from pressure-volume measurements. In all runs, the pressure and pressure differential were measured during flow and after flow was stopped. Both cocks on the cell were closed simultaneously in order that the initial shut-in pressure be as near to the flow pressure as possible. If the shut-in pressure was sufficiently high, the top cock of the cell was opened, and the system was allowed to expand to atmospheric pressure. The increase in volume was measured. If the initial pressure was low, water was admitted, compressing the gas to a sufficiently high pressure. Expansion was then permitted.

Knowing the total pore volume, the amount of water in the sand (from the resistivity measurements), the solubility constants of the gas in the two liquid phases, and the vapor pressure of the aqueous phase—since the vapor pressure of the nonaqueous phase was negligible—these measurements permitted a direct calculation of the gas content. The formulas used were rigorously derived from the assumptions:

1. The free gas obeys the perfect gas law.
2. The amount of dissolved gas is proportional to its pressure.
3. Phase equilibrium exists at all times.

TABLE 1.—*Properties of Fluids Used*

Property	Water (N/4 NaCl)	Kerosene	Kerosene-motor Oil[a]	Nitrogen
Specific gravity	1.01	0.800	0.853	
Viscosity (77°F.), cp.	0.90	1.67	18.2	0.018
Solubility of nitrogen[b]	0.0152	0.120	0.087	
Surface tension of oil, dynes per cm		27.8	30.0	
Interfacial tension, oil-water, dynes per cm		31.2	20.0	

[a] 55 per cent motor oil (S.A.E. No. 50), 45 per cent kerosene, by volume.
[b] Cubic centimeters nitrogen at 77°F. and 1 atm. per c.c. liquid per atm. (at 1 atm. and 77°F.).

The physical properties of the fluids used are listed in Table 1. The solubility of nitrogen in water was taken from the International Critical Tables. Its solubility in each of the oils was measured.

Experimental Technique.—In making a series of runs, the cell was first packed with a weighed quantity of dry, screened sand. The system was flushed with carbon dioxide, then with water so that the pore space would be filled with water. The permeability to water was then measured. The porosity was computed from the known volume of sand in the cell of known dimensions. Packings with several sands were made in the course of this work. The values of the porosities, permeabilities, and properties of the sands are given in Table 2.

TABLE 2.—*Properties of Sands Used*

Runs No.	Sieve Size, U. S. Std.	Permeability, Darcys	Porosity, Per Cent
1–20	100–200	7.0	44
21–27	100–200	6.0	42
28–31	100–200	5.6	41
32–34	80–100	16.2	42
35–106	100–200	5.4	41

A run consisted in permitting gas, oil, and water to flow through the cell until equilibrium was considered to have been reached, as evidenced by constancy of flow rates of the three fluids in the efflux, steadiness of static and differential pressures, and uniformity of resistance of the six sections of the cell. Then expansion measurements were made as previously described.

EXPERIMENTAL RESULTS

Table 3 summarizes all of the experimental work. Each run presents three sets of data: the composition of the pore space, the composition of the stream, and the relative permeabilities to the three phases. The nomenclature used is as follows:

K', relative permeability to given phase, the ratio (as per cent or fraction) of the effective permeability to that phase to the homogeneous fluid permeability of the sand.
R, fraction or percentage of given component in effluent from sand.
S, saturation of given component, fraction or percentage of total pore space.
μ, viscosity of given component, centipoises.
Subscripts: o, oil; w, water; g, gas.

Fig. 2 shows the first of the sets; each point locates the run on the composition diagram, which shows at a glance the region of "explored compositions."

To present the second set of data in a method analogous to the *R-S* curves of the two-phase investigations—curves where the fraction of one component in the stream was plotted against the fraction of that component in the pore space—would involve contours on a triangular diagram, connecting points of the same fraction of water in the flowing stream, and similar

TABLE 3.—*Experimental Results*

Run No.	Saturations			Relative Permeabilities			Stream Compositions			Pressure Differential ΔP Mm. Hg	Remarks
	S_g	S_o	S_w	K'_g	K'_o	K'_w	R_g	R_o	R_w		
6	0.157	0.411	0.432	0.0001	0.124	0.046	0.059	0.553	0.388	48	a
7	0.158	0.419	0.423	0.0010	0.085	0.025	0.418	0.372	0.210	72	a
8	0.216	0.360	0.424	0.0047	0.072	0.019	0.800	0.133	0.067	85	
10	0.306	0.279	0.415	0.042	0.036	0.022	0.981	0.009	0.010	92	
11	0.158	0.504	0.338	0.0013	0.122	0.006	0.466	0.490	0.044	49	a
12	0.127	0.547	0.326	0.0005	0.198	0.007	0.185	0.761	0.054	41	a
13	0.236	0.456	0.308	0.021	0.107	0.005	0.942	0.053	0.005	81	
14	0.274	0.425	0.301	0.058	0.075	0.004	0.984	0.014	0.002	68	a
16	0.210	0.234	0.556	0.0009	0.013	0.141	0.230	0.037	0.733	54	a
17	0.265	0.259	0.476	0.028	0.009	0.067	0.952	0.003	0.045	65	a
18	0.337	0.263	0.400	0.043	0.005	0.031	0.984	0.001	0.015	71	a
19	0.238	0.199	0.563	0.0021	0.006	0.139	0.415	0.013	0.572	60	a
20	0.226	0.192	0.582	0.0008	0.003	0.153	0.207	0.007	0.786	102	
21	0.041	0.014	0.945	0	0	0.760	0	0	1.000	27	a
22	0.004	0.148	0.848	0	0.026	0.824	0	0.016	0.984	13	a
24	0.073	0.226	0.701	0.0006	0.013	0.271	0.099	0.022	0.879	36	a
25	0.064	0.397	0.539	0.0003	0.082	0.081	0.095	0.315	0.590	54	a
26	0.073	0.629	0.298	0.0003	0.196	0.0006	0.108	0.887	0.005	42	a
28	0.054	0	0.946	0.0008	0	0.846	0.045	0	0.955	17	a
29	0.081	0	0.919	0	0	0.758	0	0	1.000	39	a
30	0.027	0.664	0.309	0.0001	0.306	0.006	0.019	0.948	0.033	37	a
35	0.583	0	0.417	0.152	0	0.030	0.996	0	0.004	62	a
36	0	0.404	0.596	0	0.222	0.124	0	0.488	0.512	211	d
37	0	0.560	0.440	0	0.334	0.038	0	0.822	0.178	258	d
38	0.111	0.246	0.643	0.0010	0.0095	0.203	0.183	0.020	0.797	102	
39	0.135	0.154	0.711	0.0002	0.0022	0.280	0.030	0.004	0.966	240	
40	0	0.695	0.305	0	0.659	0.0004	0	0.999	0.001	119	
41	0.250	0.574	0.176	0.015	0.317	0	0.814	0.186	0	153	
42	0.503	0.321	0.176	0.199	0.058	0	0.997	0.003	0	192	
43	0.592	0.244	0.164	0.342	0.0091	0	0.999+	0.0003	0	228	
44	0.671	0.165	0.164	0.424	0.0034	0	0.999+	0.0001	0	194	
45	0.499	0.337	0.164	0.324	0.006	0	0.998	0.0021	0	176	
46	0.510	0.220	0.270	0.336	0.0017	0.0002	0.999+	0.0006	0.00001	159	
47	0.458	0.247	0.295	0.216	0.0022	0.0026	0.999	0.0011	0.0002	196	
48	0.534	0.197	0.269	0.238	0.0006	0.0011	0.999	0.0003	0.00009	177	
49	0.442	0.239	0.319	0.224	0.0015	0.0048	0.999	0.0007	0.0004	172	
50	0.575	0.150	0.275	0.294	0.0002	0.0003	0.999+	0.00001	0.00002	127	
51	0.503	0.212	0.285	0.300	0	0.0027	0.999+	0	0.0002	134	
52	0.537	0.161	0.302	0.304	0	0.0029	0.999+	0	0.0002	128	
53	0.526	0.154	0.320	0.292	0	0.007	0.999+	0	0.0005	135	
54	0.421	0.208	0.371	0.292	0	0.012	0.999	0	0.0008	129	
55	0.455	0.107	0.438	0.192	0	0.041	0.995	0	0.005	154	
56	0.432	0.091	0.477	0.194	0	0.052	0.995	0	0.005	142	
57	0.362	0.106	0.532	0.153	0	0.091	0.988	0	0.012	146	
58	0.388	0.081	0.531	0.123	0	0.091	0.985	0	0.015	160	
59	0.285	0.076	0.639	0.072	0	0.184	0.950	0	0.050	155	
60	0.428	0.063	0.509	0.091	0	0.076	0.983	0	0.017	174	
61	0.553	0.058	0.389	0.218	0	0.020	0.998	0	0.002	113	
62	0.547	0.064	0.389	0.244	0	0.019	0.998	0	0.002	112	
63	0.597	0.049	0.354	0.334	0	0.009	0.999	0	0.0006	88	
64	0.446	0.249	0.305	0.176	0.0099	0.0041	0.999	0.0008	0.0006	116	
65	0.547	0.210	0.243	0.231	0.0037	0.0004	0.999+	0.0002	0.00004	85	
66	0.571	0.173	0.256	0.249	0.0016	0.0006	0.999+	0.00007	0.00005	85	
67	0.526	0.219	0.255	0.258	0.0048	0.0053	0.999+	0.0002	0.00004	83	
68	0.568	0.155	0.277	0.310	0.0012	0.0018	0.999+	0.00004	0.00001	66	a
69	0.432	0.303	0.265	0.217	0.037	0.001	0.998	0.0019	<0.00001	71	a
70	0.407	0.341	0.252	0.125	0.068	0	0.994	0.0059	<0.00001	105	
71	0.417	0.311	0.272	0.152	0.046	0	0.997	0.0033	0.0001	89	
72	0.323	0.404	0.273	0.098	0.147	0	0.984	0.016	<0.00001	98	
73	0.487	0.333	0.180	0.122	0.0633	0	0.994	0.0057	<0.00001	284	
74	0.645	0.175	0.180	0.375	0.0081	0	0.999+	0.0002	<0.00001	163	
75	0.411	0.411	0.178	0.200	0.098	0	0.995	0.0054	<0.00001	202	
76	0.341	0.475	0.184	0.092	0.212	0	0.974	0.026	<0.00001	227	
77	0.323	0.490	0.187	0.026	0.246	0	0.906	0.094	<0.00001	286	
78	0.244	0.546	0.210	0.016	0.342	0	0.738	0.262	<0 00001	186	
79	0.272	0.503	0.225	0.0031	0.299	0	0.481	0.519	<0.00001	324	
80	0.277	0.493	0.230	0.0015	0.291	0	0.315	0.685	<0.00001	328	
81	0.211	0.609	0.180	0.0004	0.302	0	0.104	0.896	<0 00001	275	
82	0.151	0.666	0.183	0.0011	0.509	0	0.173	0.827	<0.00001	187	
83	0.202	0.608	0.190	0.0006	0.488	0	0.097	0.903	<0.00001	211	
84	0.113	0.636	0.251	0.0004	0.517	0.0032	0.397	0.537	0.066	202	b
85	0.120	0.615	0.265	0.0003	0.481	0.0039	0.371	0.538	0.091	216	b
86	0.356	0.315	0.329	0.068	0.080	0.016	0.998	0.0007	0.002	93	b,c
87	0.323	0.262	0.415	0.056	0.051	0.040	0.985	0.001	0.014	175	b
88	0.410	0.353	0.237	0.106	0.017	0.0013	0.995	0.002	0.003	95	b,e

TABLE 3.—(*Continued*)

Run No.	Saturations			Relative Permeabilities			Stream Compositions			Pressure Differential ΔP Mm. Hg	Remarks
	S_g	S_o	S_w	K'_g	K'_o	K'_w	R_g	R_o	R_w		
89	0.329	0.458	0.213	0.060	0.102	0.0008	0.998	0.0017	0.0003	140	e
90	0.290	0.505	0.205	0.052	0.166	0.0005	0.996	0.0003	0.0037	150	e
91	0.156	0.644	0.200	0.0019	0.464	0.0005	0.800	0.196	0.004	159	e
92	0.296	0.509	0.195	0.0047	0.446	0.0003	0.774	0.220	0.006	265	e,c
93	0.426	0.349	0.225	0.090	0.066	0.0007	0.999+	0.0007	0.0001	89	e
94	0.426	0.336	0.238	0.099	0.058	0.0008	0.999+	0.0004	0.0001	87	e
95	0.461	0.306	0.233	0.130	0.026	0.0006	0.999+	0.0001	0.00001	98	e
96	0.345	0.430	0.225	0.051	0.128	0.0006	0.998	0.0018	0.0002	116	e
97	0.242	0.553	0.205	0.015	0.318	0.0002	0.825	0.174	0.001	195	e
98	0.297	0.279	0.424	0.037	0.032	0.057	0.970	0.0005	0.030	106	e
99	0.242	0.254	0.504	0.007	0.015	0.093	0.889	0.001	0.110	137	e
100	0.196	0.329	0.475		0.040	0.072				168	e,b
101	0.207	0.440	0.353	0.003	0.137	0.017	0.855	0.040	0.105	273	e
102	0.223	0.577	0.200	0.0005	0.345	0.0004	0.115	0.883	0.002	120	
103	0.171	0.456	0.373	0.0004	0.233	0.028	0.087	0.749	0.164	70	a
105	0.156	0.297	0.547	<0.001	0.058	0.138	0.206	0.145	0.649	96	
106	0.044	0.177	0.779	<0.001	0.012	0.617	0.064	0.010	0.926	42	a

[a] ΔP low. Point given less than full weight in correlation.
[b] ΔP uncertain due to fluctuations of ± 4 mm. Hg.
[c] Doubtful whether equilibrium was attained. Point given less than full weight.
[d] Doubtful values failed to check two-phase work.
[e] Blend of kerosene and motor oil used.

contours for each of the other fluids. In two-phase systems there is, in general, a rather small range of S values over which the R values change from a small fraction to a large fraction; i.e., the curves are characterized by having small slopes except in a relatively narrow range where the slope is very high. In a three-phase system, this would correspond to contours widely spaced over most of the region and compressed in a relatively small region. This was found to hold true. The difficulties attending mapping such contours is apparent. Fig. 3 presents one contour for each phase. However, it shows clearly the regions of pore-space composition where the flowing stream is essentially one phase, or two phases, and where three phases are present in appreciable proportions.

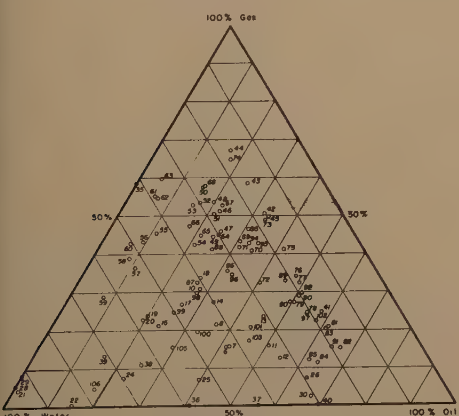

FIG. 2.—MASTER PLOT SHOWING SATURATIONS FOR EACH RUN. NUMERALS ARE RUN NUMBERS.

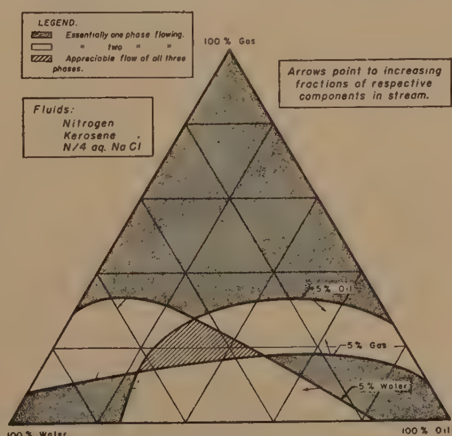

FIG. 3.—APPROXIMATE LIMITS OF SATURATIONS GIVING 5 PER CENT OR MORE OF ALL COMPONENTS IN FLOW STREAM.

The third set of data is presented in three figures, one for each phase. The relative permeability to water was found to be a function of the water saturation only

(Fig. 4). The relative permeabilities to gas and to oil, however, were found to be dependent on the saturations of all three phases (Figs. 5 and 6). Contours of equal relative permeabilities, which will be called

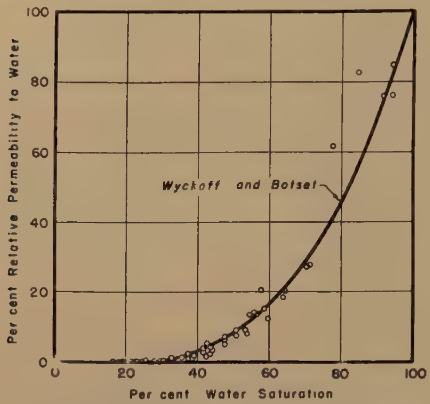

FIG. 4.—RELATIVE PERMEABILITY TO WATER AS FUNCTION OF WATER SATURATION.

"isoperms," were drawn in these figures. Boundary points were taken from the two-phase work.[1,2] Considerable spread of data was encountered in the relative perme-

FIG. 5.—K'_g, RELATIVE PERMEABILITY TO GAS AS FUNCTION OF SATURATION.

Curves are lines of constant permeability as per cent relative permeability.

abilities to gas and to oil; the isoperms of Figs. 5 and 6 represent a smoothing out of the data points of Table 3. The spread for the relative permeability to water was much less, the points falling close to a smooth curve that closely approximates those previously found for the water-gas and oil-water systems.[1,2]

Errors.—Of the several sources of error, two are outstanding: (1) dead space in the

FIG. 6.—K'_o, RELATIVE PERMEABILITY TO OIL AS FUNCTION OF SATURATION.

Curves are lines of constant permeability as per cent relative permeability.

cell, i.e., space not filled with sand; and (2) failure to reach equilibrium. The first is inherent in the design of the apparatus and at times may result in errors as high as 6 per cent in the computed oil and gas saturations. The second is thought to introduce errors of about 2 per cent in the computed relative permeability to oil. This could have been overcome by extending the time of the run, but frequently a compromise was necessary on this point, and a run had to be stopped before equilibrium was completely attained.

The existence of a pressure gradient along the cell caused but slight error, as the mean pressure was measured. The gas volume flowing in unit time across boundaries normal to the direction of flow increased toward the effluent end, both because of expansion of free gas and because of gas coming out of solution. By decreasing the gradient, this effect could be made negligible.

No attempt was made to accomplish this because the effect appeared relatively unim-

portant and there were two good reasons for using a high gradient. Greater accuracy was possible in computing relative permeabilities and the "boundary effect" was reduced when the gradient was high.

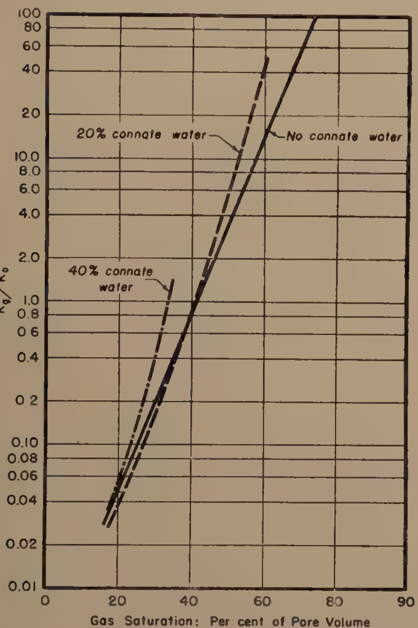

FIG. 7.—EFFECT OF CONNATE WATER ON RELATION BETWEEN RATIO K'_g/K'_o AND GAS SATURATION.

The term "boundary effect" refers to a discontinuity in the capillary properties of the system existing at the effluent end of the cell. In the body of the sand, capillary forces act uniformly in all directions, thus canceling each other. But at the end, net forces persist, which tend to prevent the water, or sand-wetting phase, from leaving the cell. This results in an accumulation of water in the downstream portion of the cell. If the pressure gradient is high, these capillary forces are relatively unimportant but at very slow rates of flow, at low gradients, the effect is disturbing.

Errors due to inaccuracies in measurements were negligible compared to the lack of reproducibility that is characteristic of this type of work. The electrical measurements were reproducible to ± 1 per cent; the shut-in pressure measurements to better than 1 per cent. Fluctuations of the manometer levels during flow reduced the accuracy of these measurements considerably. These fluctuations varied greatly from run to run. Bad jittering of the levels occurred in the region of appreciable three-phase flow. When the flow of one phase was low, there was comparative steadiness.

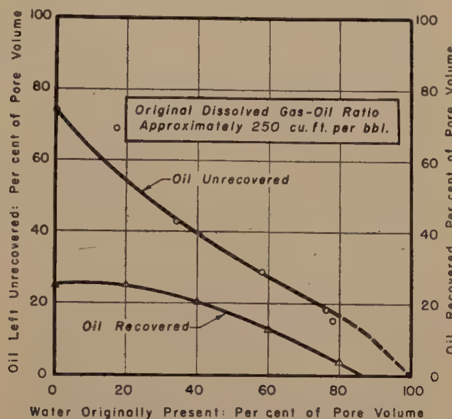

FIG. 8.—INFLUENCE OF CONNATE WATER ON OIL PRODUCTION BY GAS EXPANSION.

SUMMARY OF EXPERIMENTAL DATA

1. The relative permeability to water is determined by the water saturation alone, and is not affected by the introduction of an additional nonaqueous phase (Fig. 4).

2. The relative permeability to gas in three-phase flow is slightly less than would correspond to the same gas saturation in two-phase flow (Fig. 5).

3. The relative permeability to oil varies in a more complex manner, being in some regions less and in others more than for the same oil saturations in two-phase flow (Fig. 6).

4. The isoperms for all components are independent of the viscosity of the oil phase. Points determined using kerosene and points using the more viscous blended oil fall along the same isoperms.

5. The presence of appreciable amounts of all three phases in a flowing stream in equilibrium with the fluid in the pore space is limited to a relatively small region of pore composition.

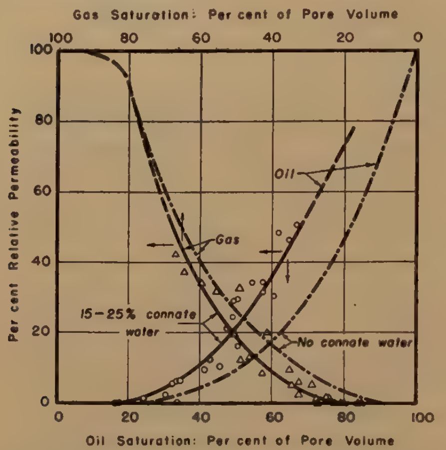

FIG. 9.—PERMEABILITY-SATURATION CURVES FOR OIL AND GAS AT 15 TO 25 PER CENT CONNATE WATER.

Discussion of Results

Effect of Connate Water on Recovery of Oil

It is possible, by regarding unsteady flow of fluid mixtures as a succession of steady flow states, to predict in part the behavior of reservoirs from steady-state simultaneous-flow data obtained in laboratory studies like the present one. The heretofore available data for simultaneous steady flow of gas and oil were obtained on sands that contained no connate water. However, since the presence of connate water in many oil sands is now recognized, it is of particular interest to discover whether its presence will seriously affect recoveries calculated from steady-flow data.

In oil production by gas drive, the gas-oil ratio flowing in the sand is

$$\frac{K'_g}{K'_o}\frac{\mu_o}{\mu_g}$$

In the absence of connate water, it is found that the ratio K'_g/K'_o increases so sharply with increasing gas saturation that excessively high gas-oil ratios usually are encountered by the time the gas saturation has reached about 25 per cent. Since continued production at high ratios quickly exhausts the available gas, it is usually predicted that in gas-expansion production the oil recovery, corrected for shrinkage, will be about 25 per cent or less of the reservoir pore volume. The effect of connate water on the relation between the ratio K'_g/K'_o and gas saturation therefore is the point of interest. Fig. 7, constructed from the data of this report, shows that the presence of 20 and 40 per cent connate water alters this relation only slightly, hence it is to be predicted that the presence or absence of connate water is not an important factor in the recovery of oil by the gas-expansion mechanism.

The substantial independence of gas-drive oil recovery of connate water has been confirmed by direct laboratory experiment. In Fig. 8 are shown the results of a series of such experiments. In each experiment sand held in a high-pressure bomb was filled with a mixture of oil and "connate" water. The oil (kerosene) was previously saturated at 1000 lb. per sq. in. with natural gas. The contents of the bomb were then allowed to produce slowly through a discharge valve. The data show that the oil recovered varied only slightly over a considerable range of connate-water saturations. This is in agreement with findings reported by Muskat and Botset.[4]

It must, of course, be realized that if the oil recovered by gas drive is independent of connate-water saturation, the oil remaining unrecovered must vary inversely as that saturation. For this reason, estimation of the connate-water saturation is of primary importance where secondary recovery methods are to be considered.

Finally, it should be pointed out that lack of effect of connate water on the relation between gas saturation and the ratio K'_g/K'_o does not imply lack of effect on the individual relations between gas perme-

ability and gas saturation and oil permeability and oil saturation. Fig. 9 presents a comparison of the relative permeability-saturation curves for oil and for gas with and without connate water. It may be seen that at 20 per cent connate water both curves have been displaced from their positions at no connate water.

Flow Mechanism

In many instances, possession of a clear mechanistic picture of a process assists in its understanding. In the present case, it is considered that the water completely surrounds each grain of sand, existing at very low water saturations as a film around the grains. When more water is present, it is believed to segregate first as rings around the points of mutual contact of the sand grains; these rings grow and finally coalesce as the water saturation is increased. In the absence of gas, at high oil saturations the oil is believed to exist as a continuous web or network enclosing and enclosed by the water-covered sand grains. As the oil saturation is decreased, the narrower portions of the oil web constrict and finally pinch off, thus making the web more diffuse. As this process goes on, portions of the oil web become isolated from the main body of oil, existing as discrete globules. This picture is in agreement with the concepts of Smith.[5] In flowing conditions, the system behaves as though the oil and water flowed smoothly, each through its portion of the liquid webs, without rupture or distortion of interfaces; i.e., the flow appears to be filamental rather than globular. At very low oil saturations, however, some globular flow seems likely.

Where gas is present, the mode of water flow is unchanged, but since the gas tends to occupy the central portions of the intergrain spaces, where the oil also is driven by capillary forces, interference between oil and gas in flow appears likely. Visual examination under the microscope shows the presence of an oil film (in some cases containing a very small amount of finely divided water) through which oil flows around each gas bubble. It is not clear whether all gas bubbles are connected. However, the gas bubbles are observed to move jerkily, as opposed to the generally smooth flow of water (and of oil when gas bubbles are absent or stationary). This jerky motion of the gas implies similar motion of at least part of the oil, which therefore would be expected to move faster than in the absence of gas at the same oil saturation. Likewise, presence of the oil should act as a partial hindrance to gas flow; both of these conclusions are borne out by the curves of Figs. 5 and 6.

Finally, the increase in oil permeability at constant oil saturation as the water saturation is increased from zero is clearly due to the shifting of the oil into parts of the intergrain spaces where it may flow more freely. The water introduced tends to occupy the sharply curved parts of the pores, forcing the oil into the central space vacated by gas. Since fluid in the sharply curved parts of the pores moves only with difficulty, and that in the center moves readily, the result is an increase in oil permeability.

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2. M. C. Leverett: *Trans.* A.I.M.E. (1939) **132**, 149.
3. H. G. Botset: *Trans.* A.I.M.E. (1940) **136**, 91.
4. M. Muskat and H. G. Botset: *Trans.* A.I.M.E. (1939) **132**, 172.
5. W. O. Smith: *Physics* (1933) **4**, 425.

DISCUSSION

H. G. Botset,* Pittsburgh, Pa.—Obviously a tremendous amount of work was required to obtain the data presented in this paper, and the authors are certainly to be congratulated on having made a valuable contribution to our knowledge of porous flow phenomena in thus extending experimental studies to the problem of three-phase flow. These experiments confirm and amplify in a satisfactory manner the picture obtained from earlier experiments with two phases, and thus indicate that we

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* Gulf Research and Development Co.

really have an adequate qualitative picture of the phenomena involved in porous flow.

The spread of the saturation data of Fig. 2 is of some interest. It is presumed that the authors attempted to get saturations covering the entire range of the diagram and yet it will be noted that, although oil and gas saturations as low as 2 or 3 per cent were obtained, there are no water saturations below about 17 per cent. This minimum water saturation is to be expected, as it agrees with results obtained on two-phase studies, where it was found impossible to obtain water saturations below about 15 per cent. At this saturation the permeability to gas, in the two-phase studies, was virtually 100 per cent of the homogeneous fluid permeability. It would appear that in two-phase flow a criterion of the minimum water saturation is the point at which the gas permeability reaches 100 per cent of the homogeneous fluid permeability. In two-phase experiments on a consolidated sand this point was reached at a water saturation of about 25 per cent. Therefore one might expect that if a similar three-phase study were made on the same consolidated sand no water saturation below about 25 per cent would be obtained, with a corresponding alteration in the other three-phase relationships.

Finally, the concentration of the two-phase and three-phase flow areas into the lower part of Fig. 3 is further proof of the difficulty of obtaining high recovery by gas drive alone, since at gas saturations above approximately 35 per cent the flowing fluid is almost entirely gas. This emphasizes the importance of taking all possible advantage of structural factors in oil-field development.

Effects of Temperature and Pressure on Rheological Properties of Cement Slurries

By R. Floyd Farris*

(New York Meeting, February 1940)

A thorough knowledge of the behavior of cement slurries under elevated temperatures and pressures is necessary in order to solve properly the many problems presented in deep-well cementing operations. In the earlier days of the petroleum industry the depths of wells were shallow as compared to those of today, and the subsurface temperatures and pressures were not of sufficient magnitude to affect seriously the problem of proper control of cement-slurry properties. Today, however, the search for new reserves has extended drilling to such depths that bottom-hole temperatures of more than 200°F. and bottom-hole pressures of 3000 to 5000 lb. are not uncommon. Moreover, there is every indication that within the next few years wells will be drilled to even greater depths and bottom-hole temperatures and pressures will be correspondingly higher than those with which we are concerned today.

It has been realized for some time that the behavior of cement slurries at high temperatures and pressures might be very different from that at atmospheric temperature-pressure conditions, but while the temperature effects have been investigated with a reasonable degree of thoroughness, the pressure effects have received little public attention.

While the trend toward deeper drilling may make changes in cementing technique and the choice of cements imperative, it was the purpose of this investigation to consider factors having a bearing on the latter, only secondary consideration being given, for the present, to details of technique and equipment for oil-field use. More specifically, the purpose of this work was to consider the effect of temperature and pressure upon the behavior of cement slurries.

Although it has long been recognized that cements thicken and set rapidly with increasing temperatures, practical methods for the quantitative determination of these effects are comparatively recent developments. In 1935 Silcox and Rule[1] presented such a method, describing apparatus designed to measure the consistency-time relationship of cement slurries at relatively high temperatures. The practical importance of this apparatus in furnishing useful data for the evaluation of cement slurries for cementing operations has been emphasized in various technical publications by such writers as E. L. Davis,[2] I. F. Bingham,[3] and J. E. Weiler.[4] A paper describing the numerous tests now used to evaluate cements for oil wells was presented in 1939 by W. W. Robinson.[5] Robinson describes the Consistometer and the Thickening-Time Tester, showing similarity of data from the two devices, and points out that the purpose of each apparatus is to determine the allowable time that a cement may be pumped at a given temperature. At the present time, however, it is believed that results from the Thickening-Time Tester and the Consistometer have not given a

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* Stanolind Oil and Gas Co., Tulsa, Oklahoma.

[1] References are at the end of the paper.

complete picture of the behavior of cement slurries under subsurface conditions, because they do not show the effect on cement slurries of elevated pressures in conjunction with high temperatures.

Fig. 1.—High-pressure Consistometer.

In this connection, it is interesting that while the literature contains few data concerning the effect of pressure on the setting of cement, it does present an interesting fact[6] from which much can be deduced; that is, that the system of cement and water undergoes a diminution in total volume during the setting process. It would appear reasonable to expect that any pressure applied to this system would tend to accelerate the progress of the system along the same path as the normal setting action. Thus, in accordance with Le Chatelier's principle, an increased pressure would result in more rapid stiffening and setting of cement. Of course, such an effect would be reflected in the consistency-time relationships of cement slurries at the higher pressures. It is also reasonable to believe that the setting of cement under high pressure might affect the development of strength in the cement. This effect probably proceeds as a result of acceleration of the normal reactions of cement in hydrating and setting.

Since high pressure considerably reduces the volume of entrained air bubbles and produces a slurry of greater density, it was first thought that this fact might partly account for the quicker setting action of cements under high pressure. A test designed to remove a large portion of the entrained air from the slurry by vacuum mixing indicated that removal of entrained air in cement slurries does not decrease the differences in thickening time that result from different test pressures.

Apparatus

To carry on this investigation, a high-pressure consistometer was designed to permit accurate measurement of the consistencies of cement slurries at temperatures up to 250°F. and pressures up to 6000 lb. per sq. in. Suitable provisions were made in the consistometer to give temperature control of plus or minus one degree Fahrenheit. High pressures were held without any difficulty to within 10 lb. of the test pressure, which was considered sufficiently accurate for this work. A stirring device was designed which would permit uniform stirring of cement slurries of consistencies varying from extremely thin paste to viscous plastics. The time that a cement slurry will stir before the rapid stiffening occurs will vary somewhat with the type and rate of shear in the high-pressure consistometer, but for the present tests a constant rate of shear was established, so that all tests might be comparable. In the pres-

ent study maximum test pressures were limited to 5000 lb. per sq. in., because it was felt that, in spite of the fact that actual maximum slurry pressures often exceed this value in the field, any interesting effects of pressure would probably be evident under the test conditions used. A general view of the high-pressure consistometer is shown in Fig. 1.

Calibration of High-pressure Consistometer

Since the physical properties of cement slurries vary with rate of shear, it is necessary that the rate of shear be fixed at some practical value before an attempt is made to evaluate slurry consistencies. To arrive at this, the energy consumption due to fluid flow of a unit volume of cement was calculated for different common casing sizes, different rates of slurry injection, and various slurry consistencies. Calculations were next made to determine the relation of the energy consumed per unit volume of slurry in the high-pressure consistometer to rotational speed of the stirring mechanism for slurries of various consistencies. The data gave families of curves from which it was possible to make direct comparisons of slurry input in a given size of casing to consistometer speed at equal rates of shear. In short, assuming an average field input to be 20 sacks per minute mixed to an average consistency of 20 "poises," the calculated data indicated that a consistometer speed of 67 r.p.m. is equivalent to pumping such a cement into 7-in. o.d. 24-lb. casing, and a speed of 27 r.p.m. is equivalent to pumping the cement into 9-in. o.d. 38-lb. casing. The shearing rate used in the present experiments was determined by averaging the above two consistometer speeds, thus arriving at 47 r.p.m. This figure is probably nearer correct for 7-in. casing than it is for 9-in. casing, owing to the failure of cement slurries to act as true fluids. The presence of false body systems and the tendencies toward plug type flow in large pipe, such as casing, are very likely to give a shearing rate less than the calculated data would indicate. Further discussion will be given to this subject later in this paper.

It should be pointed out that the shearing rate in the high-pressure consistometer at a stirrer speed of 47 r.p.m. differs considerably from the rate of shear obtained in the now common "ice cream freezer" type of consistometer. The shearing rate in the latter is approximately one-half the shearing rate in the former, by actual measurement. The calibration of such apparatus makes it easy to lose sight of the difference in the rates of shear between the various instruments. Calibration of both devices is essentially the same and consists of a process of holding the speed of stirring and all other variables constant, and plotting the work done in stirring a true nonthixotropic fluid against the viscosity of that fluid. By repeating this step, using fluids having different viscosities, it is possible to obtain a curve showing the viscosity of a fluid in the consistometer in terms of work done in stirring that fluid under the conditions of calibration. Therefore, when different consistometers of various designs are calibrated in this way, it is possible to obtain fairly good viscosity readings while the rate of fluid shear may vary widely in the different instruments.

Although the consistometer is calibrated with true viscous fluids, using accepted units of viscosity (poises), the term "viscosity" will not be applied to cement slurries in this investigation, in recognition of the fact that cement slurries do not behave as true fluids. The thickness or body of cement slurries will be indicated by the term "consistency" henceforth in this report. However, the term "poise" will be retained simply for convenience to express the units of consistency and to reflect the implications of the calibration.

Limit of Mobility

It is convenient to compare cement slurries at some common consistency in order to evaluate the relative abilities of the

different cements to remain as fluid slurries for a time sufficient to allow proper placement in a cementing operation. In order that the test results may have the greatest practical significance, the slurry consistency selected for the basis of comparison should be equal to the maximum practical slurry consistency that can be handled easily by cementing-equipment pumps. This being done, even within close approximations, the stirring time in the consistometer will probably bear a reasonably close relation to the time that a cement slurry may be pumped, provided the other variables are held within reasonable limits. Previous investigators, using the atmospheric pressure type of consistometer, suggested that a slurry consistency of 40 "poises" be used as an "estimated limit of pumpability"; therefore cement slurries in this investigation will be compared at a consistency of 40 "poises" and the time elapsed after the water is mixed with the dry cement to the time when the slurry acquires a consistency of 40 "poises" will be referred to as the stirring time.

"Estimated limit of mobility" will be substituted for the phrase "estimated limit of pumpability" herein, because it better implies that slurry consistency and available pumping force are not the only limiting factors, and it will be shown later in this discussion that although it is convenient to compare cement slurries at some upper consistency limit such as 40 "poises," the practical and recommended limit to which a cement may be pumped will be somewhat less than that consistency after proper consideration is given to other factors.

Classification of Cements

The cements investigated were classified as standard Portland cement and oil-well cements. All special cements for oil wells designed to be slow-setting (retarded) at high temperatures, whether accomplished by mill processing or chemical treatment, are referred to herein as oil-well cements. The common cements for construction work, which have not been processed for any special use, are termed standard Portland cements.

Methods and Procedure

In making consistency tests, the procedure for preparation of the sample and the operation of the high-pressure consistometer is briefly described as follows:

The cement to be tested is carefully sampled by means of a brass tube, 1¼-in. by 3-ft., which is used to obtain a cylindrical section through the entire body of the cement in the bag. After thorough mixing of the dry cement, the correct amount is weighed out from the portion sampled as described above. The mixing water (Tulsa City tap water, in the present case) is measured and used at 90°F. The slurries are mixed in the proportion of 40 parts (by weight) of water to 100 parts of dry cement. The water and cement are uniformly mixed for exactly 2 min. and the slurry placed in the consistometer pressure chamber, which is at the desired test temperature. Stirring is started, the chamber made pressure-tight, and the desired test pressure applied to the cement slurry. Consistency measurements are then made at definite time intervals until the slurry has stiffened to a consistency of 70 or 80 "poises" and is very rapidly approaching its initial set.

Results of Tests

The test results accumulated in this investigation have been reduced to graph form, and the curves and families of curves resulting are described as follows:

Fig. 2 shows the consistency curves resulting from a series of pressure-consistometer tests made using a standard Portland cement designated as cement A. These tests were made at temperatures of 100° and 180°F., and cover a pressure range from atmospheric to 5000 lb. per sq. in. It is

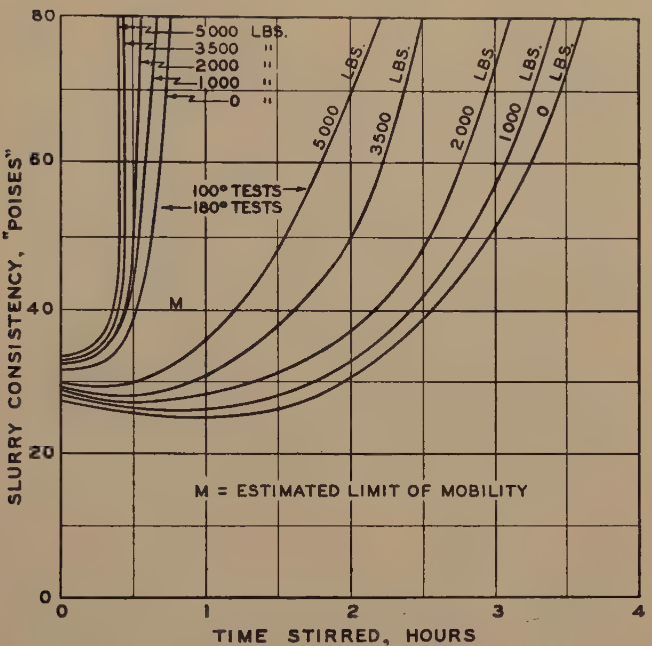

FIG. 2.—CONSISTOMETER TESTS ON PORTLAND CEMENT A AT 100° AND 180°F. WATER 40 PER CENT.

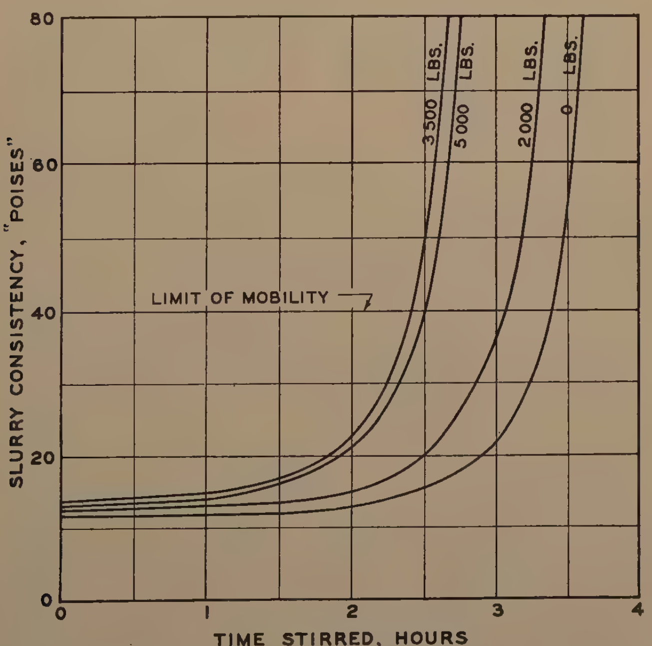

FIG. 3.—CONSISTOMETER TESTS ON OIL-WELL CEMENT B AT 180°F. WATER 40 PER CENT.

apparent that pressure hastens the stiffening of the slurry and greatly reduces the stirring time. At 100°F., the effect of increasing the pressure from atmospheric pressure to 5000 lb. per sq. in. reduced the stirring time to the 40 "poise" limit by 1 hr. 40 min., or approximately 54 per cent. The tests at 180°F. indicate that this type of cement would be practical for use in oil wells only at much lower cementing temperatures. The stirring time in these tests was reduced 9 min., or approxi-

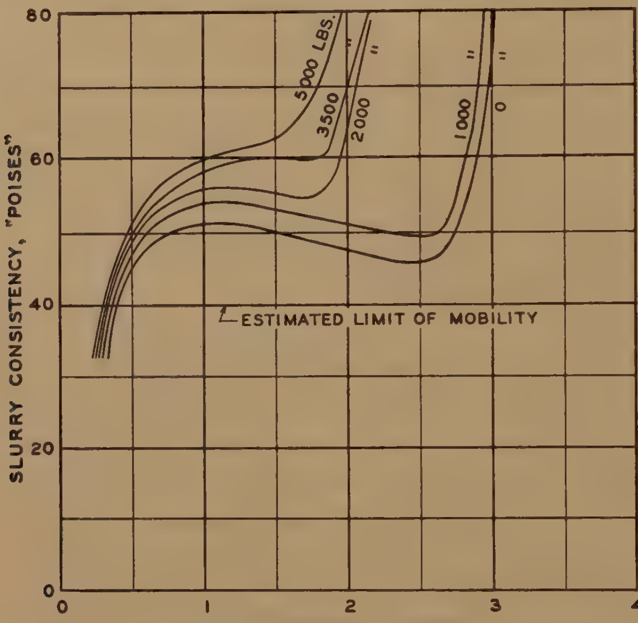

FIG. 4.—CONSISTOMETER TESTS ON OIL-WELL CEMENT B AT 220°F. WATER 40 PER CENT.

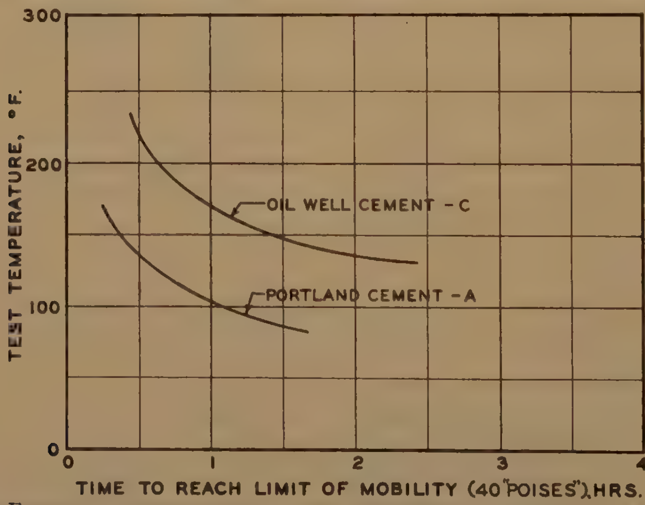

FIG. 5.—EFFECT OF TEMPERATURE ON LIMIT OF MOBILITY AT 5000 POUNDS PRESSURE.

mately 29 per cent, by increasing the pressure from atmospheric to 5000 pounds.

Fig. 3 shows a group of pressure-consistometer tests on oil-well cement B at 180°F. This cement, being a special cement for of the slurry increased rapidly soon after test conditions were applied. Although this cement did not enter the final stiffening period for some time, the fact that it did not remain below 40 "poises" indicates that the conditions imposed are too

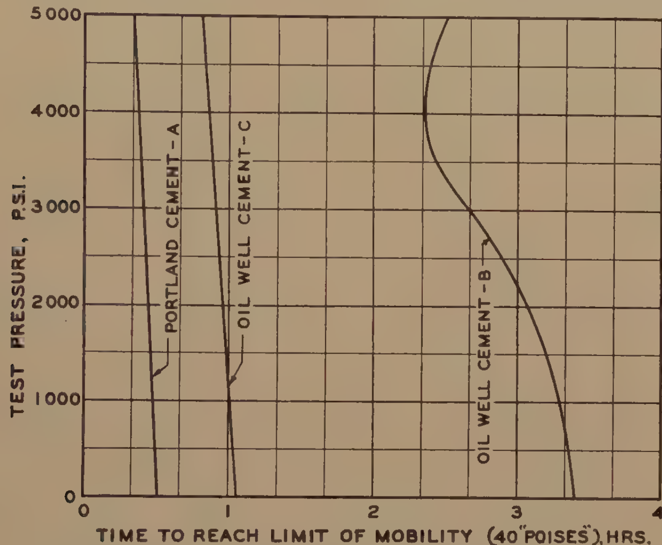

FIG. 6.—EFFECT OF PRESSURE ON LIMIT OF MOBILITY AT 180°F.

high temperatures, will be observed to be much more resistant to a temperature of 180°F. than the previous standard Portland cement. The fact that this cement was more resistant to high temperature did not prevent the slurry from stiffening more rapidly at high pressures. The pressure increase from atmospheric to 5000 lb. per sq. in. reduced the stirring time by 59 min., or approximately 27 per cent. In other words, an increase in pressure up to 3500 lb. decreased the stirring time of this cement, but the 5000-lb. test stirred slightly longer than the 3500-lb. test. A series of check tests were made to corroborate this reversal in trend. This peculiar phenomenon cannot be explained at present. It appears to be a characteristic of this cement at this particular condition of temperature and pressure.

Fig. 4 shows the results of tests made on oil-well cement B at 220°F. The consistency rigorous for this cement. The reverse trend noted in Fig. 3 did not appear in these tests.

Fig. 5 summarizes the effect of temperature on the limit of mobility at 5000 lb. pressure for two cements. The curves were obtained by plotting the time stirred to the intercept of the 40 "poise" line against temperature at 5000 lb. Oil-well cement C is shown with Portland cement A since the tests on cement B provided only two points for a curve.

Fig. 6 summarizes the effect of pressure on the limit of mobility for three cements at 180°F. The change in direction of the curve for oil-well cement B between 3500 and 5000 lb. pressure is another expression of the reversal effect of pressure described under Fig. 3.

The graphical data repeatedly indicate that the stirring time on all cements was greatly reduced owing to pressure alone. The reduction in stirring time caused by

increasing the pressure from atmospheric to 5000 lb. per sq. in. averages 31.5 per cent for the three oil-well cements, 41 per cent for the standard Portland cement, or an average of 35 per cent for all cements. In other words, the stirring time of the average cement, based on atmospheric consistometer tests now commonly used, is probably overestimated since the time value at 5000 lb. per sq. in. is approximately 35 per cent less than the stirring or pumping time at atmospheric pressure.

Up to this point cements have been compared largely on the basis of their ability to remain at a consistency below 40 "poises" for a certain time, called the stirring time, at certain conditions of temperature and pressure. There is no reason to believe that an arbitrary limit of mobility, such as 40 "poises," should be the only standard for evaluating oil-well cements. Certainly a cement slurry consistency sufficiently low to permit placement is the first requisite, but other qualities such as strength of the set cement, uniformity of the slurry, and the ability of the slurry to displace drilling fluids properly should also be taken into account.

Effect of Agitation on Strength of Set Cement

In this connection, a series of tests was made to determine the strength of the set cement after the slurries had been subjected to different periods of stirring at constant temperature and pressure. Special equipment was devised to operate in conjunction with the high-pressure consistometer, which would permit high-pressure and high-temperature slurries in the consistometer to be transferred into a high-pressure specimen mold and cured without loss of pressure.

The stirring time of the cement to be tested was divided into convenient intervals and the slurry at the end of each interval was transferred from the consistometer and cured under test pressure and temperature for 72 hr. At the end of that time, the pressure was released and the cured cement cylinders, 2 by 4 in., were tested for compression strength. The molds accommodated three such cylinders per test run. Tests were made on both standard Portland cement and oil-well cement at different temperatures and pressures. Since the results were found to show essentially the same trends, oil-well cement B was selected to represent the typical result. Fig. 7 shows the time-consistency relationship of oil-well cement B at 5000 lb. pressure and 140°F. and the compression strength of the cured cement at 72 hr., from the slurries after different periods of stirring.

These tests indicate that the strength of the set cement is not greatly affected by stirring or agitation while the slurry is fluid, but the strength of the set cement is definitely injured if the slurry is stirred, pumped, or otherwise strongly agitated after the slurry starts to stiffen. The results also show that the rate of strength reduction increases as the rate of stiffening increases. This indicates that if cement slurries at 5000 lb. pressure and at higher temperature, such as 180° to 220°F., are pumped after they begin to stiffen rapidly, the cement will suffer injury much greater than that shown in these tests. While these results are not unexpected ones, it is interesting nevertheless to know that the detrimental effects of shearing a slurry after thickening begins are just as prevalent at the higher pressures as they are at atmospheric pressure.

In order to utilize the protection that goes hand in hand with high cement strengths, slurries at high temperatures and pressures should not be pumped after rapid stiffening begins. That point in Fig. 7 would be at 2 hr. stirring, whereas the stirring time to the arbitrary 40 "poise" limit is 3 hr. Therefore it is suggested that in actual practice the pumping time allowed for cement slurries should not be as long as has been estimated previously.

Plug-type Motion in the Consistometer

All of the previously discussed consistometer tests were made with a stirring mechanism that forced the slurry to remain viously outlined procedure. Tests were made on all the cements previously mentioned, and oil-well cement C was selected as representing the typical result.

Fig. 8 shows what happened when a slurry was not subjected to vigorous agita-

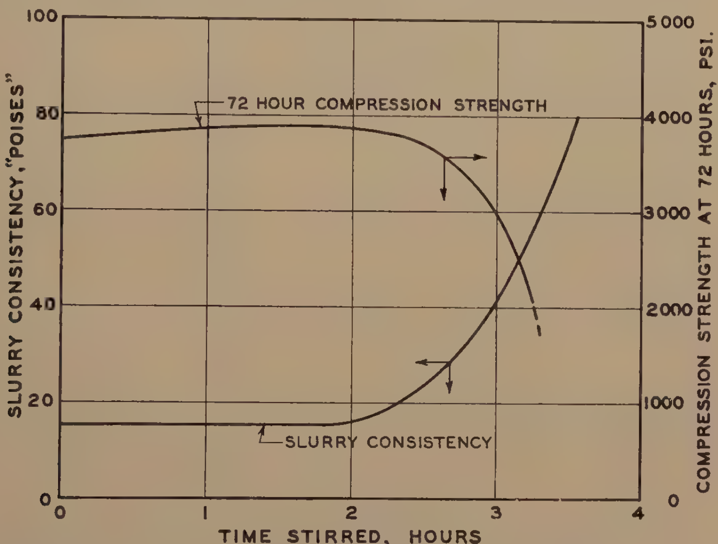

Fig. 7.—Strength consistency vs. stirring time on oil-well cement B at 5000 pounds pressure and 140°F.

uniform throughout the tests. Since the flow of cement in oil-well casing might not be subject to such thorough agitation, it was desirable to study a condition that probably corresponded more closely to practical conditions. This study was made in the following manner.

The original stirring mechanism was exchanged for one that offered greater resistance to the passage of slurry through the paddle openings. Further, the paddle afforded an amount of shear that increased with the radial distance from the center of the consistometer. It also gave a slightly greater shearing rate at the top than at the bottom of the consistometer. The over-all shearing rate, however, was just slightly less than that obtained with the original paddle at the same rotational speed.

Consistometer tests with this stirring device were made according to the pre-

tion in the center. From the beginning of the tests to points *A* the slurry stirred uniformly, but as the slurry stiffened it became more and more difficult for it to pass through the paddle restrictions. At point *A* the slurry ceased to pass through the paddle, causing the entire cement body to whirl as a plug. This plug-type motion, shearing only at the wall, was lubricated by the free water present, so as to indicate a false reduction in consistency. As the setting of the cement progressed further, the apparent reduction in consistency was regained and the apparent consistency continued to increase.

Examination of the cement after the test was finished showed that the main body of the cement had reached its initial set, but the thin film shearing at the wall of the consistometer was still in a plastic state.

Plug-type motion in the consistometer is accelerated and magnified by increasing the pressure to 5000 lb., as shown in Fig. 8.

The effect of the slightly greater shearing rate at the top of the consistometer was to cause plug-type motion to develop first at the top. When the condition of the slurry was examined at points A (in repeat runs), it was found that the plug was in the process of forming and that at the bottom of the consistometer, where the shearing rate was less, the plastic cement plug had not formed. The portion of the slurry that "froze" to the paddle was found to be in a soft, semiplastic state, and in the general shape of a cone, with base at the top of the consistometer. This indicated that where there was weaker agitation at the center of the consistometer, the greater the shearing rate at the wall, the greater would be the tendency for plug-type motion to develop.

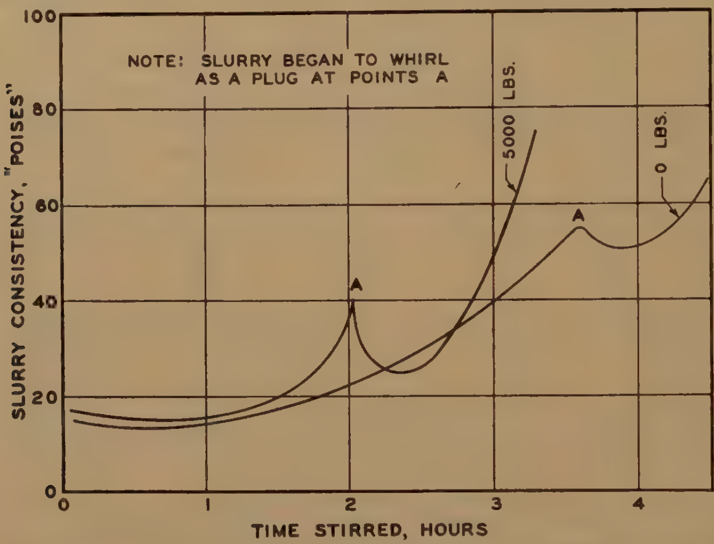

FIG. 8.—CONSISTOMETER TESTS ON OIL-WELL CEMENT C AT 140°F. WATER 40 PER CENT.

All oil-well cements showed the same phenomena at 140° to 220°F., and at all pressures. The Portland cement, however, stirred uniformly throughout the tests, which were, of course, of somewhat lesser duration than for the slow-setting cements.

Discussion of Results

The results obtained with the high-pressure consistometer must be interpreted in the light of an evaluation of the method and a study of the relationship of the tests to practical cementing operations in the field.

It will be well to remember that these tests are essentially a comparison of the consistency-time relationships of the different cements under comparable conditions of temperature, pressure, water-cement ratio, and rate of shear from the time of mixing to a stiffness above which the cement is assumed to be incapable of being pumped. If the variables are controlled, or varied in the test procedure so that they bear a close relation to practical conditions, the consistometer stirring time under a given set of conditions should correspond reasonably closely to the maximum pumping time under the same conditions in field practice. It is understood, of course, that for this statement to be correct the temperature and pressure in the consistometer must correspond to some representative average

bottom-hole cement-circulation temperature and pressure.

Arriving at a suitable test temperature for such work is a problem that has received much attention recently. Robinson[5] reviews an empirical method, which has been found applicable to California fields. Whether or not it is generally applicable to other fields is a question that cannot be answered at this time. The test temperatures discussed herein are recognized as being somewhat higher than the maximum slurry temperature that would be reached in a cement job on a well having a static bottom-hole temperature equal to the test temperature.

If the consistometer tests may be assumed to be an indication of the performance of cement slurries in field practice, the test results clearly indicate that each of the cements tested has definite limitations. Without reviewing specific cases, certain cements appear to be practical at 5000 lb. pressure and 140°F. maximum slurry temperature, but at the same pressure and 180°F. they stiffen so rapidly that they are wholly impractical. On the other hand, a cement that appears satisfactory at 5000 lb. and 180°F. is retarded too much to be satisfactory at the same pressure and 140°F., since it is desirable that the slurry set reasonably soon after coming to rest, in order to minimize water loss from the slurry and deterioration of the cement from salt water. In short, the cements vary widely when compared on a common basis, yet each cement may be used within a definite temperature-pressure bracket in preference to other cements. It is fortunate that this variation exists, since it affords the consumer an opportunity to choose a cement for each particular set of conditions found in practice, except possibly for extreme conditions of temperature and pressure.

Present cementing conditions sometimes exceed the actual test performance of cements that are recommended by the manufacturers, for high-temperature and pressure applications. For example, the consistometer tests showed that some of the cements stiffen rapidly at a pressure of 5000 lb. and 180°F. and not one remained below a consistency of 40 "poises" for any practical length of time at 5000 lb. pressure and 220°F. Under normal conditions actual cementing temperatures may not be so high, but frequently delays occur during cement jobs, so that the slurry may approach normal formational temperatures, necessitating placement after the slurry has begun to stiffen rapidly. The strength tests showed that it is detrimental to strength to stir or pump a stiffening slurry, therefore the obvious conclusion is that none of the cements tested would be satisfactory for field use at pressure and temperature conditions of 5000 lb. and 220°F.

The practical solution of the high-temperature and pressure cementing problem will probably come from the development of cements so effectively retarded at higher temperatures and pressures that the slurry may be pumped easily into place before rapid stiffening begins.

During this investigation some time was given to the subject of cement-set retarders. Among the more effective set retarders, one allowed a cement slurry to stir at a low consistency at 180°F. and 2000 lb. pressure for well over 7 hr. before final stiffening began. This cement was over-retarded, but the test points to the fact that it would probably be practical at much higher temperatures and pressures. Further, these tests show that it is possible to meet demands of consumers for cement retarded for higher temperatures and pressures.

In addition to the importance of having a slurry that may be pumped to final placement before stiffening begins, it is also desirable to know something of the quality of the slurry and its ability to displace drilling fluids properly.

All of the cements, except the standard Portland cement, show the undesirable characteristics of giving up free water, and

of allowing the cement particles to fall partially from suspension. The seriousness of free water separation from cement slurries is difficult to evaluate properly. It contributes to nonuniformity and will, in all probability, act in a manner that will cause a poor cement job in a well. Water separation during a cement job may cause water pockets or bridges in the set cement, or water may be lost to porous formations under pressure, leaving a slurry that might set up much more rapidly than the initial slurry. Water separation from cement slurries is generally an inherent characteristic, and some observers have attributed it to the combined effects of sedimentation and a kind of syneresis. However, since both phenomena are generally thought of as characteristic of a static condition, the theory does not satisfactorily explain water separation from a cement slurry in a state of continuous agitation.

Another physical characteristic of cement slurries, which may have a great bearing on the success of a cement job, is a kind of premature stiffening due to the existence of what colloid chemists know as a false body system. When the ordinary proportion of water is mixed with cement, a thin, almost waterlike slurry is formed. If, after thorough mixing, the slurry is allowed to stand in an open vessel at room temperature for a few minutes, observation will reveal that the slurry has been transformed into a semisolid or a plastic state. The vessel may be inverted without causing any slurry movement but if the mass is agitated it will again form a reasonably thin slurry. The longer the mass is allowed to stand in an undisturbed plastic state, the more difficult it is to break it up. On the contrary, if the slurry is subjected to prolonged stirring from the beginning, the tendency for false body systems to develop is greatly reduced.

False body systems are greatly influenced by high temperature. Certain consistometer tests at high temperatures could not be made because false body systems developed so quickly that the stirring mechanism could not be made to rotate even with a stirring force sufficient to shear a fluid having a viscosity of more than 300 "poises." This condition was an extreme case, where the high temperature caused the false body condition to develop into a flash set, but it demonstrates that these effects may have a great bearing on the success of a cement job.

The behavior of cement slurries while being pumped through casing is so intricately governed by the rate of shear, and by temperature and pressure conditions, that the type of flow and the effect of the existence of false body systems are matters of conjecture. However, it seems that in the light of the advances made in the study of the properties of cement slurries, all the contributing factors point to the possible occurrence of plug-type flow in oil-well casing. Some of the factors that may contribute to plug flow are: (1) the tendency to develop a false body condition while pumping in large casing where agitation is rather weak; (2) the tendency of the slurry to give up free water, thereby lubricating the walls of the casing, and forming a fluid envelope through which the plug may slide easily; and (3), the fact that increasing temperature and pressure accelerate the other factors.

The fact that plug-type flow may develop at high temperatures and pressures where a poor quality of cement is used does not mean that such a condition would stall the pumps and prevent landing of the plug. On the contrary, laboratory tests (Fig. 8) have proved that a slurry may be moved more easily when moved as a solid mass, shearing only at the wall, than when uniformly stirred, which indicates that a cement not testing up to par may be pumped in plug flow to bottom, then thick semiplastic cement stringers may push up through the drilling fluid by way of least resistance and another bad cement job be "buried." If well conditions are not particularly rigorous,

perhaps no future difficulty will arise; on the other hand, if much depends on the strength and uniformity of the cement around the casing, failure may introduce endless trouble and expense.

Again, the need for cements that are more effectively retarded at high temperatures and pressures is indicated. Retarding should be accomplished without introducing an accelerated false set, the cement particles should be held in suspension, slurries should not give up free water or "bleed," and should have a low, uniform consistency during weak agitation. The oil-well cements tested mixed to slurries of low initial consistency, but on standing or during weak agitation developed false body conditions and gave up large quantities of free water. As shown in Fig. 8, when incompletely agitated all of the oil-well cements developed plug-type motion in the consistometer and gave up considerable free water, whereas ordinary Portland cement remained uniform and did not give up any appreciable quantity of free water. Therefore it appears that many of the present oil-well cements are retarded at the expense of other very desirable qualities. If a cement could be retarded either by chemical treatment or by other processing, so that it would retain all the desirable qualities of Portland cements, it is very likely that the tendency toward plug-type flow at high temperatures and pressures would be greatly reduced.

The nearest practical proof and example of the inability of some cements to remain properly fluid while being pumped down long strings of casing at high temperatures and pressures is often indicated when the plug is drilled. In deep wells of high temperature, 1000 ft. or more of cement scale is often encountered before the drill bit reaches the cement plug. This probably is due to the false body and flash-set phenomena. Too frequently the driller reports that the cement plug is "drilling soft." Cores taken while drilling the plug frequently show a cement that is chalky in appearance, soft, weak, porous, permeable, and, in general, closely resembling the laboratory specimens that were stirred through the stiffening period.

Application of Results

In order to obtain the maximum protection that a cement job can afford, individual consideration should be given to every operation. Since there are no all-purpose cements, data of the type presented herein will aid the engineer in selecting the cement best suited for his particular problem. Individual consideration of each problem will permit the selection of a cement that will produce a slurry to meet the following conditions:

1. It must have an initial consistency that will permit easy handling by the pumps at the lowest practical water-cement ratio.
2. It must remain at a low consistency for a period of time sufficient to permit placement before rapid thickening begins.
3. It must thicken and take its initial set reasonably soon after coming to rest, in order to avoid contamination by brines and drilling fluids.
4. It must develop reasonable strength in the period during which the well is shut down for this purpose.

Conclusions

From the foregoing, it is concluded that.

1. The effect of high pressure is to greatly accelerate the stiffening and setting of a cement slurry.
2. The effect of high temperature in connection with high pressure is to further accelerate the stiffening and setting of a cement slurry.
3. At a pressure of 5000 lb. and 180°F., most of the cements tested stiffen too rapidly to permit proper placement in a deep well. At the same pressure and 220°F., all the cements tested stiffen beyond the limit of mobility immediately.

4. Agitating a slurry at high pressures after rapid stiffening begins is detrimental to strength of the set cement.

5. The point on the consistency-time curves where rapid stiffening begins should be regarded as the maximum recommended pumping time, instead of using any assumed viscosity or consistency limit, such as 40 "poises," as a "limit of pumpability."

6. The practical solution of many of the present and future high-pressure and high-temperature cementing problems will probably be solved when cements are improved so as to permit the placement of a uniform, mobile, and good quality slurry at any given practical high temperature and pressure.

It is beyond the scope of this paper to deal with all the factors that have a bearing on cement slurries, or to set forth a specification to be used as a guide in the selection and use of cements. It is, however, intended to point out to the users and manufacturers of cements that the hitherto neglected effects of pressure on the physical properties of slurries are actually matters of serious consideration, and to call attention to one theory—namely, the plug flow phenomenon, discussed herein—which may be used to explain why the drastic thickening effect of high temperatures and pressures have not been readily obvious from pump pressures in the field.

Acknowledgments

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Measurements of the Viscosities of Oils under Reservoir Conditions

By C. R. Hocott* and Stuart E. Buckley,* Members A.I.M.E.

(New York Meeting, February 1940)

The viscosity of the oil in the reservoir is one of the properties that influence its movement through the sand to producing wells. Measurements of viscosity, therefore, are pertinent to problems associated with well behavior and with the estimation of recoveries, and afford an indirect means for partial evaluation of various methods of controlling reservoir behavior. The effect of dissolved gases on the viscosity of crude oil has been determined,[1,2] but no data have been published on the viscosity of representative samples of reservoir oils. This paper describes a simple instrument that has been used to determine the viscosities of a number of subsurface oil samples at the temperatures and pressures existing in the reservoirs, and presents the results of the determinations for typical fields.

Construction of the Apparatus

The principal requirements of any instrument used for the examination of subsurface samples are that it be strong and simple both in design and in method of operation. Accuracy beyond that of the degree of reproducibility of subsurface samples from various wells in a reservoir or exceeding that of the common measurements of reservoir temperatures and pressures is not required. Because of the expense of procuring subsurface samples, it is necessary also that the instrument operate on a relatively small fraction of a sample, leaving the remainder for other tests, and that there be few or no failures of the equipment to cause undue delay or loss of a sample.

After preliminary experiments with a falling bullet, the results of which were not satisfactory, a simple viscosimeter was built of the rolling ball type first proposed by Flowers[3] and later used by several investigators.[4,5,6] The apparatus consists essentially of a removable, accurately bored cylindrical barrel of ¼-in. nominal internal diameter, 8 in. long, in which a closely fitting steel ball rolls through the oil with the barrel inclined at a definite angle. The ball makes contact at one end of the barrel with an insulated electrode, closing an electrical circuit, which actuates a buzzer. The measurements consist essentially in determining the time required for the ball to travel the length of the barrel.

The details of the construction are shown in Fig. 1. The barrel in which the ball rolls was made from a section of 25-caliber blank rifle barrel, specially bored to an exact uniform diameter and polished. The barrel slides snugly into a hole bored in a solid stainless-steel cylinder, an upper external shoulder of the barrel compressing a small spring, and is held in place by a hollow nut. The spring prevents the barrel from seating against the bottom of the bored hole in the cylinder, while narrow external longitudinal slots in the barrel permit fluid to flow around it and through the bottom.

The upper part of the recess in the steel cylinder is enlarged to form a tapered chamber, which acts as a reservoir for the oil and affords space for agitation to ensure

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[1] References are at the end of the paper.

equilibrium between the gas and oil. The taper permits the ball to roll readily into the barrel when the instrument is at an angle of inclination of 75°. The upper end

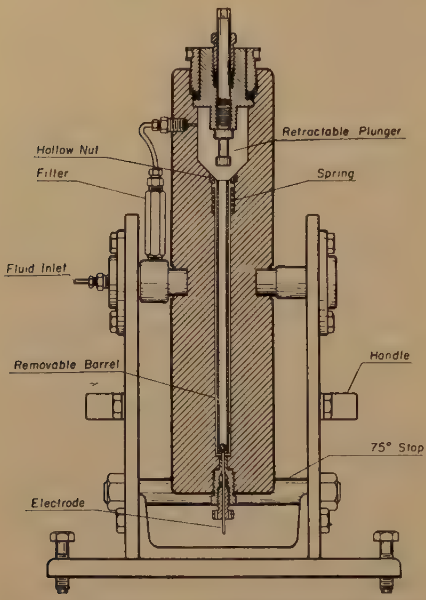

FIG. 1.—DIAGRAM OF PRESSURE VISCOSIMETER.

of the chamber is sealed by a polished piston seated on a shoulder, the closure made with a neoprene gasket of area smaller than that of the lower surface of the piston. The primary gasket compression is effected by means of a hollow nut, which slips over the piston.

A retractable plunger with a polished lower surface is screwed through the cylinder head in such a fashion that it is accessible and may be turned with a small wrench while the instrument is immersed in a high-temperature bath. While the viscosimeter is being charged with oil or the contents being agitated to bring about equilibrium, the plunger is kept partly or fully retracted. During the course of a measurement, however, the plunger is screwed into the cylinder, sealing the upper end of the barrel and simultaneously sealing the lower end of the barrel by pressing it against a gasket in the bottom of the bored recess in the cylinder. Since the pressure is at all times equal inside and outside of the roll barrel, the instrument has no pressure coefficient, and the double sealing of the barrel adequately prevents leakage during a measurement.

The steel cylinder is mounted on trunnions so that it may be rotated through an angle of approximately 330°. The trunnion bearings are set in aluminum plates, which in turn are fastened to a third aluminum plate equipped with four leveling screws. The supporting plates were set carefully perpendicular to the base plate and machined accurately with the tops parallel to the base and of the same height, to permit use of an ordinary bubble-type level in aligning the instrument for a viscosity measurement. Handles on the plates make the instrument readily portable.

The trunnion plates have one fixed stop, consisting of a cylindrical bar, which gives the barrel an angle of inclination of approximately 75° from the horizontal, and two removable positive stops at angles of inclination of approximately 23° and 11°, permitting the roll time to be varied in the ratios of approximately 4:2:1 for any given viscosity and size of barrel and ball. Additional flexibility in the roll time is obtained through the use of removable roll barrels and balls of different diameters. The roll time usually is kept between 20 and 60 sec. For the range of viscosity thus far encountered, 0.5 to 10 cp., barrels of 0.250 and 0.252-in. diameter with a ball of 0.243-in. diameter have sufficed.

The bottom of the cylinder enclosing the barrel is closed by means of an adapter nut, which carries the electrode. The electrode consists of an insulated copper wire passing through the adapter, with the pressure sealed by means of a small Bakelite cone compressed into a tapered recess and about the wire by a tapered follower ring and nut. No trouble whatsoever has been experienced with the electrode through either electrical leakage or fluid leakage in ap-

proximately a year's operation. Similar cones have been used satisfactorily for sealing silk-wrapped two-lead thermocouples through a single entrance against pressure, the Bakelite being the only material tried that would not twist off the wires during compression of the cone.

The auxiliary apparatus consists of a vacuum-tube relay and buzzer circuit for indicating the instant of contact of the ball with the electrode, a calibrated steel-tube bourdon pressure gauge, a manifold with valves for admitting and withdrawing the sample, and a water bath with electrical heating coils and thermostat. A small filter, used only when absolutely necessary, is placed in the line between the manifold and the viscosimeter in such a position that the sample will be filtered at the reservoir temperature.

Viscosity determinations can readily be made on as little as 20 c.c. of liquid. The entire system, including the viscosimeter, pressure gauge, manifold, and connecting 18-in. steel tubing requires a charge of approximately 80 c.c. of saturated subsurface oil, less than 20 per cent of the contents of the usual subsurface sampler.

Because of the small clearance between the rolling ball and the barrel, absolute cleanness is essential to successful operation. After each series of measurements, the barrel is removed, washed with ether, and polished with a silk rag, and the cylinder and connecting lines are washed carefully with ether and evacuated.

Calibration

The instrument was calibrated before use and is recalibrated from time to time with a series of fluids consisting of hexane, kerosene, a light lubricating oil, and various blends of these three materials. The viscosities of the calibrating fluids were determined with a Ubbelohde suspended level capillary instrument calibrated by the National Bureau of Standards. The densities of the calibrating fluids were determined with a pycnometer.

Calibration charts were prepared for a given size barrel and ball by plotting the absolute viscosity of each fluid against the product of the roll time and the difference in density between the fluid and the ball, according to the method suggested by Kennedy and used by Sage.[5] Typical calibration curves are shown in Fig. 2 for a barrel of 0.250-in. internal diameter and a ball of 0.243-in. diameter at the three angles of inclination.

Experimental Procedure

Measurements at reservoir temperature are made with the instrument immersed in a water bath, the temperature of which is controlled to ±0.5°F. Oil and gas are expanded into the viscosimeter, through steel tubing ⅛ in. in outside diameter, direct from a subsurface sampler of which the contents have been saturated previously. During charging, the retractable plunger is turned to a position midway between the seated and fully retracted positions, with the ball in the enlarged portion of the cylinder. The partly retracted plunger prevents the ball from entering the roll barrel but permits fluids to pass back and forth freely. The charging is done with the viscosimeter tilted to the position with the electrode up and the enlarged part of the cylinder down, so that during the initial stages of charging the oil is retained in the enlarged part of the cylinder and only gas is trapped in the barrel. As the pressure in the instrument builds up with the addition of oil and gas, the oil is resaturated by vigorous rocking of the cylinder, the ball assisting in keeping the oil homogeneous. Charging is continued until the oil in the viscosimeter is completely resaturated and the pressure considerably exceeds the saturation pressure.

The plunger is then retracted the full amount, the cylinder tilted to the 75°

inclination, the electrical system connected, and the ball allowed to enter the barrel. The falling ball acts as a pump, displacing the oil in the barrel down and out the bottom and up through the external slots in the barrel to the enlarged upper part of the cylinder. When the buzzer indicates completion of the fall, the cylinder is rotated to the reverse position and the ball allowed to roll out of the barrel, flushing the oil downward into the enlarged part of the cylinder, with the barrel replenished through the external slots. Oil is thus pumped back and forth between the barrel and the cylinder a number of times to ensure absolute homogeneity.

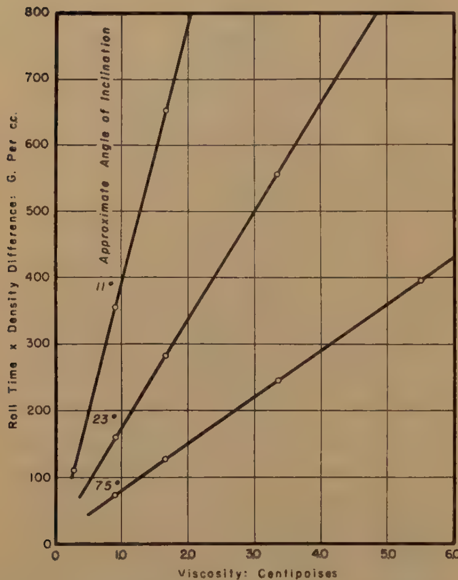

FIG. 2.—CALIBRATION CHART FOR 0.243-INCH BALL IN 0.250-INCH BARREL.

The ball is then allowed to enter the barrel and the retractable plunger is seated firmly on the top of the barrel, compressing the spring, and simultaneously seating the barrel against the lower gasket. The cylinder is rotated to approximately a vertical position with the electrode end up, sufficient time allowed for the ball to travel the length of the barrel and stop against the plunger, and the cylinder then rotated to a position just short of horizontal. The roll time is then determined by rotating the cylinder suddenly until it strikes the positive stop with the electrode down; the time for the ball to reach the electrode and sound the buzzer is measured with a stopwatch. Several determinations are made, usually at two angles of inclination. The roll times are readily reproducible to 0.2 second.

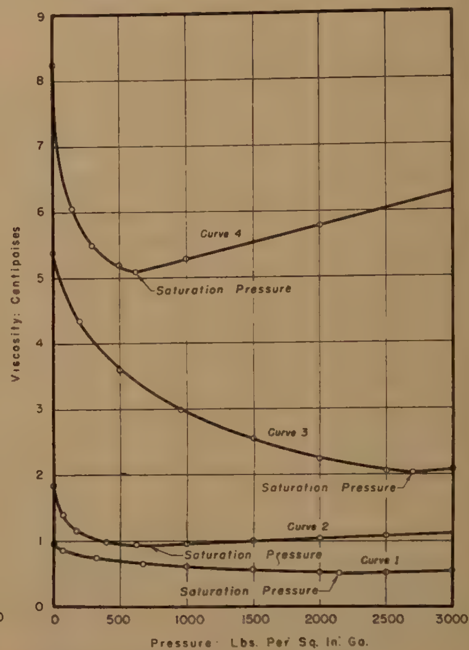

FIG. 3.—VISCOSITY OF RESERVOIR OILS.

After determination of the roll time in the supercompressed saturated oil, the plunger is retracted slightly and the pressure reduced by withdrawing a slight amount of oil through the inlet connection, the plunger is reseated and the roll time determined at the new pressure. After the saturation pressure has been reached, gas or gas and oil are withdrawn in increments with the plunger fully retracted and the

enlarged part of the chamber up. After each withdrawal, the fluids in the cylinder are agitated by rotating the cylinder back and forth from a horizontal position until the pressure becomes constant, indicating equilibrium between the residual oil and gas. The plunger is then reseated and the roll time measured as before. This procedure is repeated until the pressure in the viscosimeter has been reduced to atmospheric. The determination of the complete curve for pressure versus roll time requires usually 3 to 4 hr. Occasionally some difficulty is experienced in attaining equilibrium at atmospheric pressure, in which case the instrument is usually allowed to stand for several hours or overnight before this point is determined.

After completion of the determination at atmospheric pressure, the residual oil is drained from the pressure viscosimeter and the viscosity determined at the same temperature with the Ubbelohde viscosimeter. This furnishes a check on the operation of the pressure viscosimeter for each series of measurements.

The density of the residual oil drained from the viscosimeter is determined at room temperature with a pycnometer and corrected to the reservoir temperature with the National Standard Petroleum Oil Tables. The density of the saturated oil charged to the viscosimeter is determined separately during the course of the regular examination of subsurface samples. The density at the intermediate pressures is estimated by a linear interpolation. Since the density of the steel ball is 7.85 grams per cubic centimeter, and the density of most of the oils examined is of the order of 0.7 to 0.8 grams per c.c., estimation of the oil density to the nearest 0.07 gram per c.c. suffices to give an accuracy of 1 per cent in the density difference. The viscosity at each pressure is determined by multiplying the roll time by the corresponding density difference and reading the appropriate value from the calibration curve.

Experimental Results

Viscosity-pressure relations have been determined on a total of 41 subsurface samples from 18 different fields, covering a pressure range up to 4200 lb. per sq. in. and temperatures up to 190°F.

The results on samples from four typical Texas fields are shown in Fig. 3. In all of these determinations, the viscosity was measured at the reservoir temperature for each field, without filtering the samples, and at pressures from a value in excess of the saturation pressures down to atmospheric.

The portion of the curve above the saturation pressure represents the increase of viscosity with pressure on the homogeneous saturated oil with all of the gas dissolved. This increase of viscosity with pressure is characteristic of all liquids. The saturation pressure, or bubble point, is the pressure at which gas is first released from solution. Below the saturation pressure, the escape of gas from solution with further reduction in pressure reduction increases the viscosity of the residual oil to a greater extent than it is reduced by the pressure decline, resulting in a net increase in viscosity. The saturation pressure of the oil is thus identified in the viscosimeter through the minimum in the viscosity-pressure curve. The saturation pressures thus determined check with those determined by pressure-volume measurements on separate portions of the same subsurface sample. The increasing slope of the viscosity-pressure curve as the pressure approaches atmospheric reflects in part the increasing richness of the liberated gas and loss of the more volatile fractions of the oil. The slopes of the viscosity-pressure curves vary from field to field with the nature of the oil and its dissolved gas.

Curve 1 on Fig. 3 shows data on a sample from the Frio sand in the lower Oligocene formation in southwest Texas. The sample was taken from a depth of 4700 ft. and had a saturation pressure of 2150 lb. per sq. in. gauge at the reservoir temperature of 158°F. When flashed to atmospheric pres-

sure at 78°F., the sample yielded 803 cu. ft. of gas per barrel of residual oil. The specific gravity of the gas was 0.84 and the gravity of the oil was 45.7° A.P.I at 60°F.

Curve 2 shows data on a sample from the Palo Pinto lime in North Texas, taken at a depth of 3230 ft. The saturation pressure was 725 lb. per sq. in. gauge at the reservoir temperature of 128°F. When flashed to atmospheric pressure at 78°F., the sample yielded 293 cu. ft. of gas per barrel of residual oil. The specific gravity of the gas was 1.10 and the gravity of the oil was 41.5° A.P.I. at 60°F.

Curve 3 shows data on a sample from the Frio sand in the lower Oligocene in the Gulf Coast of Texas. The sample was taken from a depth of 5800 ft. and had a saturation pressure of 2700 lb. per sq. in. gauge at the reservoir temperature of 164°F. When flashed to atmospheric pressure at 80°F., the sample yielded 385 cu. ft. of gas per barrel of residual oil. The specific gravity of the gas was 0.65 and the gravity of the oil was 26.1° A.P.I. at 60°F.

Curve 4 shows data on a sample from the Permian lime in West Texas. The sample was taken at a depth of 4430 ft. and had a saturation pressure of 625 lb. per sq. in. gauge at the reservoir temperature of 100°F. When flashed to atmospheric pressure at 80°F., the sample yielded 191 cu. ft. of gas per barrel of residual oil. The specific gravity of the gas was 1.12, and the gravity of the oil was 29.7° A.P.I. at 60°F. The liberated gas contained about 19 per cent by volume of hydrogen sulphide.

Conclusion

A simple rolling-ball viscosimeter has been constructed, which has been used successfully for routine determinations of the viscosity of subsurface samples of oil at reservoir temperatures and pressures.

The instrument is adaptable to the measurement of a wide range of viscosities through positive variation of the roll angle, variation of the diameter of the barrel, and variation of the size of the ball.

It has been found, through examination of a large number of subsurface oil samples, that the viscosity of an oil is a minimum at the saturation pressure and that the release of dissolved gas attending reduction of the reservoir pressure results in increased viscosity of the residual oil. Because of the nature of the variations of the viscosity with pressure, direct measurements on subsurface samples appear to be the only feasible method for determining the viscosity of any particular oil under reservoir conditions.

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Pressure Distribution about a Slotted Liner in a Producing Oil Well

By Frank G. Miller,* Junior Member A.I.M.E.

(New York Meeting, February 1940)

The lower cost of producing oil from naturally flowing wells compared with production costs accruing from artificial lifting methods has stimulated much research, with the joint purpose of extending the natural flowing life of wells and of increasing the productivity of small wells. The laboratory investigation described herein was made to determine the effect of a slotted liner on the pressure gradient in the vicinity of the wall of a flowing well. Flow restrictions caused by the liner induce energy losses between the oil-bearing formation and the inside of the liner, which may be reduced by improved liner design, and thereby the flow capacity of wells may be increased. These losses have been evaluated for rectangular slots of different sizes, and means are suggested for reducing them.

The dearth of information concerning the nature of the flow of fluids from unconsolidated sands through small openings in the walls of pipes—as represented by the flow of oil from an oil sand into a slotted liner—is acknowledged. Although the benefits to be realized by operators through the use of optimum liners is just beginning to be recognized generally, Coberly[1] in 1937 pointed out that the functioning of screen casing is an important factor in the production of oil. From his study on the selection of size of oil strings for wells in California, Parks[2] concluded, in part, that the perforated section of the oil string deserves continued study, especially with respect to the selection of perforations.

The growing use of gravel packing resulting from certain research findings lends even more significance to the problem of selecting optimum liners, as the application of these methods usually requires slotted liners or other kinds of perforated liners.

The present study was made to obtain further information for the guidance of engineers and operators in selecting slotted liners and to develop a laboratory method that may be used in analyzing possible pressure conditions surrounding most types of perforated casings used in producing oil wells, so that the present inadequate fund of knowledge on this important subject may be expanded.

Discussion of Problem

At the beginning of the investigation the following assumptions were made regarding bottom-hole conditions of a producing oil well and the oil-sand reservoir it penetrates: (1) Conditions of steady-state flow exist, (2) a single-phase homogeneous liquid is being produced, (3) no contaminating material (such as drilling fluid) is present between the liner and the face of the oil-bearing sand, (4) the well is vertical and completely penetrates a horizontal sand stratum of uniform thickness occurring between two impermeable strata, and (5) the flow is wholly viscous.

If the foregoing assumptions are made, with the added requirements that the sand

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[1] References are at the end of the paper.

be immobile and of constant permeability and that no liner be present, the pressure in the sand can be shown to vary with the logarithm of the radial distance from the

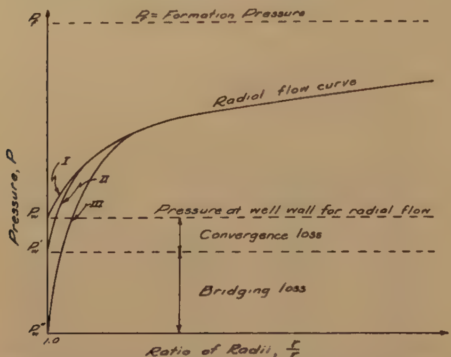

FIG. 1.—SCHEMATIC DIAGRAM SHOWING PRESSURE DISTRIBUTION NEAR WELL WALL.
All curves apply to a single flow rate.

well axis, in accordance with the radial flow equation[3]

$$P = \frac{Q\mu}{2\pi kh} \ln \left(\frac{r}{r_w}\right) + P_w \qquad [1]$$

where P is the pressure at a radial distance r from the well axis, Q the volumetric rate of production, μ the fluid viscosity, h the sand thickness, k the sand permeability and P_w the pressure at the sand face r_w, the well radius.

The pressure distribution indicated by equation 1 would not exist in the vicinity of the well wall if the sand were unconsolidated or a liner were present. For convenience in discussing the pressure distribution in the sand next to a liner, reference is made to Fig. 1, showing a schematic diagram of pressure conditions in the sand for a single flow rate. The pressure distribution for purely radial flow is shown by curve I, in which the pressure difference between some point in the formation remote from the well and some point at the sand face is $(P_f - P_w)$, P_f being the formation pressure and P_w the pressure at the well wall.

If a slotted liner is present the streamlines must converge more than they do for radial flow so that the fluid will pass into the slots. This crowding of the flow lines in the sand near the slots causes an additional loss in pressure head equal to $(P_w - P_w')$ in the diagram. Curve II indicates the pressure distribution in the sand when only the additional streamline convergence is considered and shows that the flow would be radial beyond this region of slot influence, but that the pressure gradient near the well wall would be steeper because of it. Further, the abscissa of the point where curve II starts to deviate from curve I affords a measure of the outer limit of the region of slot influence.

Actually, an unconsolidated oil sand is held back by a liner as the sand forms a bridge over each slot, even though some of the grains may have equivalent spherical diameters less than the slot widths. On a theoretical basis, it may be predicted that the sand bridge would be in the form of an arch and that the smaller grains at the arch would be wedged tightly between the larger grains. It follows that the sand bridge probably would have a lower permeability than the main sand body beyond, so that an additional loss of head would result. In contrast it may be contended with equal logic that a sand bridge could form by tight wedging of larger grains and a removal of fine grains through a slot before the actual bridging effect began. Under this condition the resulting permeability of the sand just outside a slot would be greater than that of the main sand body beyond, so that the effective head loss due to bridging could be zero or negative. Curve III, illustrating the condition where wedging of the smaller grains between the larger grains decreases the permeability of the sand at the bridge, includes both the head loss due to convergence $(P_w - P_w')$ and a positive head loss due to bridging $(P_w' - P_w'')$, so that the pressure difference between some point in the formation remote from the well and

some point at the outside wall of the liner would be $(P_f - P_w'')$. It will be apparent that curve III deviates from the radial flow curve at a distance limiting the region of slot influence and that within this region the pressure gradient is fairly steep because of the combined effect of streamline convergence and bridging.

In field practice the formation pressure (P_f) is taken as the static bottom-hole pressure, determined after a well has been shut in long enough to permit equilibrium conditions to become established in the sand. The bottom-hole pressure can be determined while a well is producing at a constant rate. This pressure is P_w'' in the diagram, if the head loss due to the "orifice action" of the slots is neglected. Head loss due to orifice action is the pressure drop that occurs across the slots even if no sand is present (similar to the pressure differential across an orifice in the flow of fluids in pipe lines), but as this loss was found to be relatively small it is neglected in this analysis.

As an aid in the discussion of experimental methods for use in determining convergence and bridging losses, the pressure-distribution curves of Fig. 1 are plotted on semilogarithmic paper in Fig. 2, with the pressure at the well wall taken as the datum.

Equation 1 indicates that the pressure curve for purely radial flow is a straight line on semilogarithmic paper and that this line terminates at point $\left(\frac{r}{r_w} = 1\right)$ and $(P - P_w = 0)$ if the well-wall pressure is taken as the datum. Curve I, Fig. 2, illustrates the pressure gradient in the sand under conditions of radial flow. If a slotted liner is present and if the hypothesis is proposed that the sand is homogeneous to the outside wall of the liner, the pressure distribution beyond the region of convergence would be represented by a straight line parallel to the radial flow curve on semilogarithmic paper, but within this region the pressure gradient would be steeper, as shown by curve II. Similarly, curve III represents the conditions where both convergence and bridging are manifest.

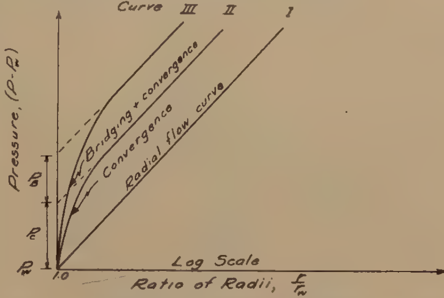

FIG. 2.—SCHEMATIC DIAGRAM SHOWING PRESSURE DISTRIBUTION NEAR WELL WALL.
All curves apply to a single flow rate.

If curves II and III are extrapolated to the pressure axis, their equation, considering one constant flow rate, would have the form

$$P - P_w = m \log\left(\frac{r}{r_w}\right) + b \qquad [2]$$

where m is the slope and b the intercept on the pressure axis. Slope m, for either curve, depends on the volumetric rate of flow, the sand thickness, the fluid viscosity, and the permeability of the sand beyond the region of slot influence. If only streamline convergence is considered, b would depend on the slot pattern and on the slot dimensions, and the magnitude of b would represent the additional pressure loss (P_C) due to convergence. In the actual case, b would depend also on the added flow resistance due to the sand bridge (assuming a positive head loss due to bridging), so that $b = P_C + P_B$ in Fig. 2.

In evaluating the experimental energy losses, data were obtained with laboratory apparatus designed for use in determining values of b (equation 2) or total losses corresponding to rectangular slots of different sizes. The part of the total loss due to convergence was computed from the results in each instance. Measurements of the outer limits of the region of slot influence

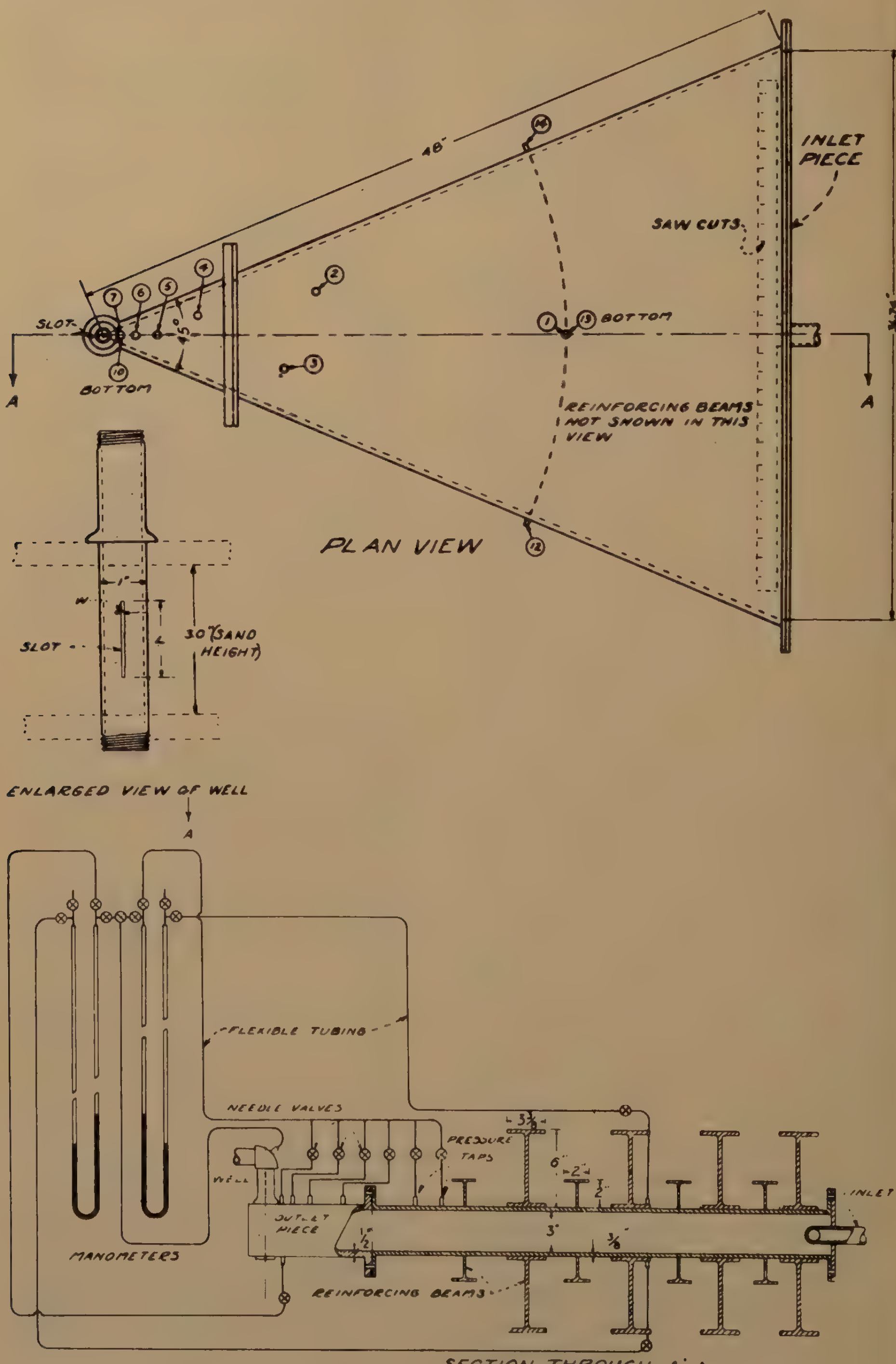

FIG. 3.—FLUID FLOW APPARATUS.

were made. Head loss caused by the slots alone (no sand present) was shown to be relatively small.

Two different sets of laboratory apparatus were used: (1) a fluid flow through sand apparatus (the prototype) and (2) an electrolytic conduction model made similar to the prototype. Each apparatus simulated the objective and was built so that the potential distribution across a radial sector adjoining the well could be measured.

Through the physical analogy of hydraulic and electric currents, the voltage potentials incident to the flow of electric current through the electrolyte in the electrolytic conduction model correspond to the pressure differentials incident to the flow of fluid through the porous medium in the prototype. However, the conducting medium of the model could be made uniform to the well wall, whereas the sand in the prototype could not, principally because of bridging over the slots. Thus the electrical model could be used to determine convergence losses alone, and the fluid-flow apparatus could be used to determine losses resulting from convergence plus bridging and losses caused by the slots alone (orifice action). Hence, experiments could be performed on both sets of apparatus and the results properly combined to show the respective losses from convergence and bridging for some rectangular slots of different sizes.

Apparatus

Fluid Flow through Sand Apparatus.—The fluid-flow apparatus (Fig. 3) was designed to simulate the flow conditions about a single slot in an actual liner. The apparatus was built so that a volume of sand of uniform thickness (3 in.) under an area in the form of a 45° sector would be drained through a single test slot in each experiment, which simulates the flow conditions about one slot in an actual liner having eight rows equally spaced about its circumference. For ease of construction, the apparatus was designed as a wedge-shaped pressure vessel (plan view, Fig. 3). Thus the sand with which the vessel was packed had the form of a triangular block 3 in. thick with two equal 48-in. sides that would intersect at the well axis if projected. The angle between the equal sides of the sand block was 45°. The triangular shape of the vessel (in contrast with the theoretical sector of a circle) did not prevent the flow in the sand from being radial some distance from the experimental well, as is shown later in the section on Experiments on Flow of Fluid through Sand.

The pressure vessel was designed so that the deflection between the upper and lower plates would be negligible during a test. The desired deflection requirements were satisfied by constructing the tank with a composite of cast and welded metal parts.

The flanged outlet piece was cast iron, and the remainder of the built-up part of the vessel was made from boiler plate with standard 6-in. I-beams and 2-in. T-beams welded as reinforcing members. The inlet piece accommodated a 1-in. pipe fabricated in the form of a T and having numerous vertical saw cuts, as shown in the sketch, to ensure adequate distribution of incoming liquid.

The brass experimental well, which has a 1-in. outside diameter and a 1/16-in. wall thickness, was machined to fit the outlet casting snugly. As only a 45° section of the lateral surface of the well could be opposite the sand in any one test several slots of preassigned lengths and widths were cut in the same well and used independently.

The pressure taps are short 1/8-in. standard pipe nipples having fine brass screens soldered to the ends that screwed into the tank, but they do not extend beyond the inner surface of the tank.

Only one manometer assembly is shown, but it was possible to change the assembly so that these instruments could be used to the best advantage in each experiment.

Description of Electrolytic Conduction Model.—In constructing the electrical analogy apparatus (Fig. 4), a wooden tank, open at the top and containing a weak solution of sodium chloride through which an electric current could be passed, was made similar to the sand-filled pressure vessel of the fluid-flow experiments, in that the depth of the electrolyte was 3 in. in the container, which had the shape of a 45° sector. The wood of the tank was treated with hot paraffin to render it nonconducting to the current. The "well" was made from a solid circular Bakelite rod 2 in. in diameter, into which vertical grooves were cut to accommodate copper strips that were analogous to slots in the prototype.

Six different strips were cemented in grooves in the same Bakelite cylinder, but each could be used independently. A copper sheet 1/16 in. thick was set vertically at the inside wall of the tank opposite the well, so that it lay along an arc of a circle (or cylinder) centered at the well axis. An electric current could be passed through the electrolyte in the tank between the sheet acting as one electrode and a copper strip in the "well" acting as the other.

An exploring probe was used to determine the voltage distribution in the tank away from the well during current flow, but was not employed to obtain potential and flow lines in the immediate vicinity of the copper strips. The probe was a copper rod about 1/10 in. in diameter, mounted on a point gauge assembly but insulated from it with Bakelite as shown in the sketch. The whole probing device as shown in the sketch was designed so that the electrolyte could be surveyed with reference to the "well" axis.

The source of power used was the 110-volt, 60-cycle local city supply. Alternating current was employed to minimize polarization at the electrodes. The wiring diagram of Fig. 4 shows schematically how the apparatus was assembled for use.

Experiments and Results

Experiments on Flow of Fluid through Sand.—Total pressure-head losses resulting from the use of slots were respectively measured for five test slots in the fluid-flow apparatus. Head losses resulting from the "orifice action" of these slots were measured independently, with no sand in the pressure vessel. The convergence losses corresponding to these slots were measured in the electrical analogy apparatus.

Three of the test slots were for two-dimensional flow; that is, each of these had a length equal to the sand thickness (3 in.). The widths of these slots, designated as *A*, *B* and *C*, were 0.010, 0.020, and 0.032 in., respectively. Slots *G* and *F* were 0.010 and 0.020 in. wide, respectively, but were for three-dimensional flow as each was only 1½ in. long. The well was 1 in. in diameter, and in each test the slot was placed vertically with its center midway between the flat upper and lower plates of the pressure vessel confining the sand.

A cleaned white beach sand from Monterey, Calif., composed essentially of quartz and feldspar grains, was packed in the apparatus before each experiment.

The results of an analysis of the test sand with standard Tyler sieves are: 0.2 per cent on 28 mesh; 10.1 through 28 and on 35; 56.2 through 35 and on 48; 30.4 through 48 and on 65; 3.0 through 65 and on 100; and 0.1 per cent through 100 mesh.

Water was used as the fluid. The particular fluid used in experiments of this kind is unimportant, as the pressure losses corresponding to other liquids of known physical properties could be computed provided Darcy's law described the flow.

The inlet end of the pressure vessel (Fig. 3) was made flat for ease of construction, but it was predicted that the flow would become radial a short distance from the inlet. Pressure differences corresponding to the highest flow rates were

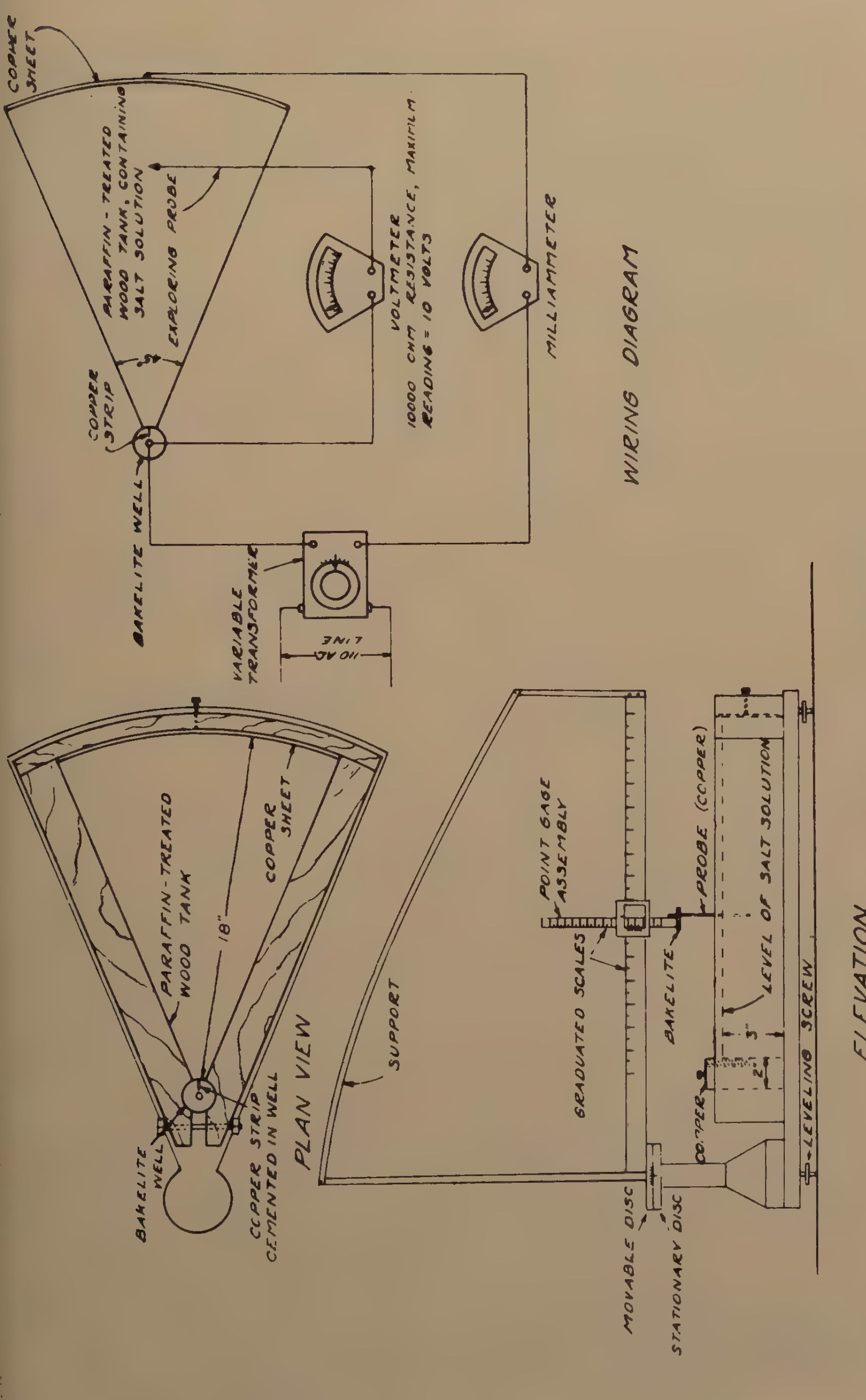

FIG. 4.—ELECTRICAL ANALOGY APPARATUS.

measured between taps 1, 12, 13 and 14 (all on an arc of a circle centered at the well axis) each time the apparatus was packed and a different slot placed opposite the sand. These pressure differences were negligible so that the flow was known to be radial between this circle and some inner circle limiting the region of slot influence.

The pressure distribution between tap 7 and tap 1, corresponding to five constant rates of flow, was determined after each test slot had been placed opposite the sand. The data collected were used to evaluate the average permeability of the sand in the radial-flow region. In this analysis a consistent foot-pound-second system of units has been used, in which permeability is expressed in square feet—admittedly an uncommon unit; hence, permeability determined in square feet has been converted to darcys (darcys times 1.062×10^{-11} equals permeability in square feet). The average permeability of the sand between taps 7 and 1 was 54.6, 55.4, 56.4, 50.0, and 65.6 darcys when slots *A*, *B*, *C*, *F* and *G*, respectively, were facing the sand.

After the permeability data or pressure-distribution data for the sand between taps 7 and 1 had been collected, the pressure losses in the vicinity of the slots were measured for various rates of flow. The low-pressure limb of the manometer was connected to a tap in the well slightly downstream from the slot (Fig. 3), and the high-pressure limb was connected to tap 7 slightly upstream from the slot and in the sand; $\left(\frac{r_7}{r_w}\right) = 2.25$, where r_w is the well radius and r_7 the distance between tap 7 and the well axis. Pressure differentials corresponding to various rates of flow, thus measured, are caused by the flow resistance between tap 7 and the well wall plus the loss caused by the "orifice action" of the slot.

The pressure-head losses caused by the slots alone for various rates of water flow were obtained with the same manometer connections, but the apparatus was cleaned of all traces of sand. The results of these experiments when compared with the results of the experiments described in the preceding paragraph indicated that a head loss caused by the "orifice action" of a slot is small compared with the corresponding loss due to the slot plus the sand out to $\left(\frac{r}{r_w}\right) = 2.25$; hence the data of these two sets of experiments were combined so that the head loss caused only by the sand between tap 7 and the well wall could be determined for any test slot and flow rate. These data, when combined, showed that some of the resulting pressure-head loss was caused by partly turbulent flow conditions in the sand just outside the slot, which indicates that the experimental flow rates were somewhat high. However, it will be significant to point out that there was no turbulent flow in the sand beyond tap 7 in any of the permeability experiments and that the total data collected were sufficient for the determination of the pressure distribution in the sand between the well wall and tap 1 for any test slot or rate of flow.

Figs. 5 and 6 illustrate results plotted on semilogarithmic graph paper for the maximum rate at which data on all slots were collected and for one lower rate. Each curve of Figs. 5 and 6 represents the best line through the respective points for the five greatest values of $\left(\frac{r_n}{r_w}\right)$, where r_n is any particular radial distance from the well axis and r_w is the well radius. The solid lines represent the radial part of the flow pertaining to the various slots, and the dotted parts of the lines are extrapolations into the nonradial region. A study of the curves reveals that the intercept on the pressure axis resulting from an extrapolation indicates the pressure loss for a particular flow rate caused by all additional flow restrictions occurring in the sand beyond the well wall.

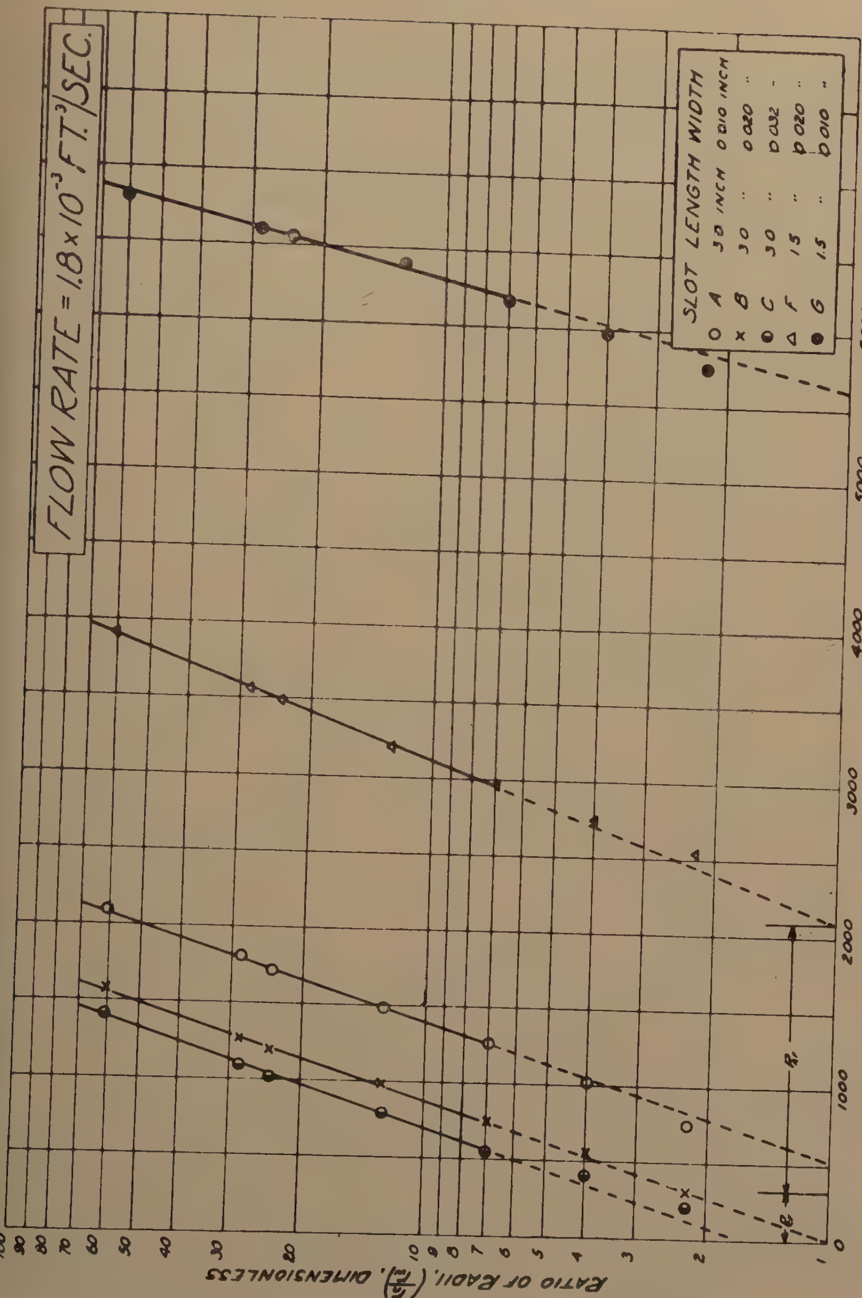

FIG. 5.—PRESSURE LOSSES IN VICINITY OF LINER WALL FOR DIFFERENT SLOTS AND ONE RATE OF FLOW.

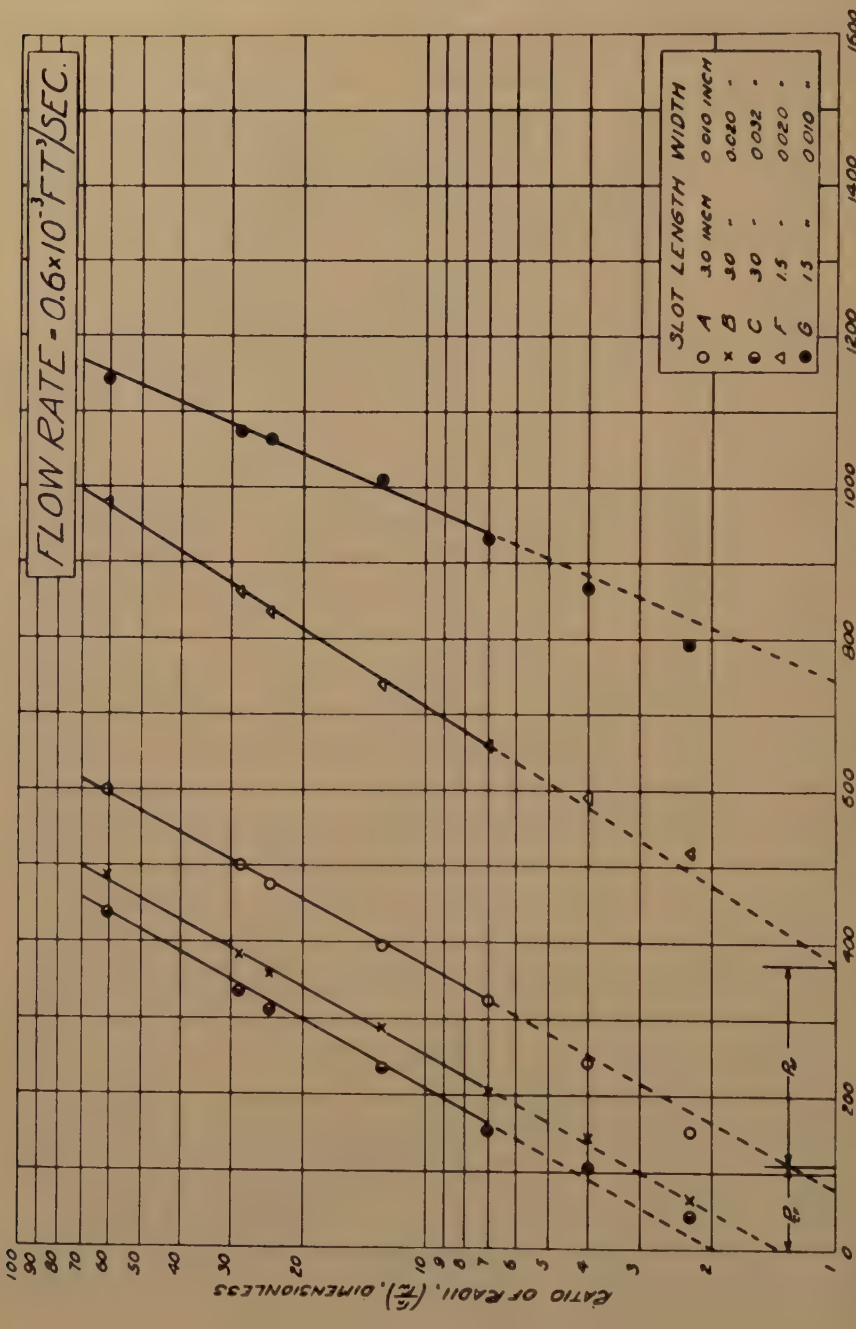

FIG. 6.—PRESSURE LOSSES IN VICINITY OF LINER WALL FOR DIFFERENT SLOTS AND ONE RATE OF FLOW.

It would not be strictly correct to compare directly the intercepts (corresponding to one flow rate) to find the effect of slot dimensions, as the viscosity of the water and the average permeability of the sand differed from test to test. However, the magnitude of the ratio of the experimental loss, obtained from the fluid-flow experiments, to the theoretical convergence loss, computed from the results of the electrical analogy experiments affords a measure of the effect of bridging and arching, as related to slot size.

Experiments with Electrolytic Conduction Model.—Six copper strips analogous to slots were tested in the electrical analogy apparatus. The strips for two-dimensional flow, designated as A, B and C, were 0.020, 0.040, and 0.064 in. wide, respectively. Their effective length was 3 in. (the depth of the electrolyte in the test vessel). The other three strips, G, F and D, also were 0.020, 0.040 and 0.064 in. wide, respectively, but only 1½ in. of their length could be exposed to the electrolyte, hence three-dimensional flow resulted in tests of these strips. The portion of a strip exposed to the electrolyte extended from the surface to a point 1½ in. below the surface. The diameter of the test "well" was 2 inches.

The dimensions of both sets of apparatus show that the electrolytic conduction model is geometrically similar to a half of the fluid-flow apparatus taken either above or below an imaginary horizontal plane passed through the center of the contained sand and equidistant from the upper and lower flat plates, provided the respective strip and slot have the same designation. Thus it is apparent that voltage differences measured in experiments with the model were exactly double what they would have been if the model had been made geometrically similar to the fluid-flow apparatus as a whole. Computations and results on the model experiments were based upon geometrical similarity, so that direct comparison could be made with the results of the fluid-flow experiments.

Fig. 7 is a representation on semilogarithmic graph paper of the results computed from the data taken on the model. In the figure, r_n is any particular radial distance from the well axis, r_w the well radius, E_n the voltage at r_n, E_w the voltage at r_w, and I the rate of current flow. The distribution of voltage was determined for various rates of current flow for each strip. The solid lines in the figure represent the radial part of the flow pertaining to the various strips, and the dotted portions of the lines are extrapolations into the nonradial region. The parallelism of the curves indicates that the specific resistance of the salt solution was the same in all experiments, so that direct comparison may be made among the test results for the strips.

Comparison is made on the basis of strip dimensions and on the relative effect of two-dimensional and three-dimensional flow for a conducting medium homogeneous to the well wall. For this purpose the values of the intercepts on the $\left(\frac{E_n - E_w}{I}\right)$ axis representing the added voltage per unit rate of current flow, due to convergence, are used. In this report such intercept values are termed convergence losses. If the convergence loss had been zero in a model experiment the current flow would have been radial to the well wall. Table 1 summarizes the electrical analogy results.

The results show that the convergence loss is not affected greatly by a twofold or threefold change in the strip width as long as the length of the strip remains unchanged; however, a comparison between strips having the same width but different lengths shows that the convergence loss about triples when the strip length is halved and the flow is changed from two-dimensional to three-dimensional.

Combination of Fluid Flow and Electrical Analogy Results.—The following equation

TABLE 1.—*Results of Experiments with Electrolytic Conduction Model*

Copper Strip	Width, In.	Length, In.	Type of Flow[a]	Ratio of Width of Slot to Well Diameter	Convergence Loss, Volts per Ampere
A	0.020	6.0	2	0.010	11.0
B	0.040	6.0	2	0.020	9.1
C	0.064	6.0	2	0.032	7.7
G	0.020	3.0	3	0.010	30.7
F	0.040	3.0	3	0.020	26.7
D	0.064	3.0	3	0.032	24.0

[a] Figures indicate two-dimensional and three-dimensional, respectively.

relates the variables of geometrically similar electrical and fluid-flow systems, provided Ohm's law and Darcy's law are respectively applicable

$$\frac{dl}{A} = \frac{k}{\mu}\frac{dP}{Q} = \frac{dE}{I\sigma} \qquad [3]$$

in which l is the length of the conductor (electrolyte or sand); A the cross-sectional area presented to flow and, in general, a function of l; k the sand permeability; μ the fluid viscosity; P the fluid pressure; Q the volumetric rate of fluid flow; E the electric potential; I the rate of electric current flow and σ the specific resistance of the electrolyte. Hence, from equation 3,

$$\Delta P = \frac{\Delta E}{I\sigma}\frac{Q\mu}{k} \qquad [4]$$

As the electrolytic conduction system was geometrically similar to the fluid-flow system, the value of some particular intercept may be taken from Fig. 7 and used to compute the pressure differential for an analogous fluid-flow system in which the fluid viscosity, sand permeability, and volumetric rate of flow are specified. For example, the intercept for copper strip F is $\left(\frac{\Delta E}{I}\right) = 26.7$ volts per ampere (Fig. 7). The specific resistance σ of the test salt solution was 6.88 ohm-feet. During the test of slot F in the fluid-flow experiments the viscosity μ of the water was 2.54×10^{-5} lb-sec. per sq. ft. and the sand permeability k was 53.1×10^{-11} sq. ft. Substituting the foregoing values with a flow rate Q of 1.8×10^{-3} cu. ft. per sec. in equation 4, and solving for ΔP, gives 335 lb. per sq. ft. as the result.

In other words, the intercept of the curve for slot F in Fig. 5 would represent a pressure difference of 335 lb. per sq. ft. if the convergence loss had been the only influencing factor. The experimental value of the intercept is 2100 lb. per sq. ft., hence the additional pressure loss resulting from the bridging of the sand over the slot and some turbulence just outside the slot is 2100 − 335, or 1765 lb. per sq. ft. The ratio of the actual experimental loss to the computed convergence loss is 2100/335, or 6.27. It follows that the relations between slot dimensions and total pressure losses would be indicated by similar ratios computed for all slots tested and both flow rates used in Figs. 5 and 6, as these ratios are dimensionless and independent of sand permeability and fluid viscosity. The results of the computations are given in Table 2.

TABLE 2.—*Summary of Results*

Rate of Flow, Cu. Ft. per Sec.	Slot Opposite Sand	Experimental Loss, Lb. per Sq. Ft.	Computed Convergence Loss, Lb. per Sq. Ft.	Experimental Loss Minus Convergence Loss, Lb. per Sq. Ft.	Ratio of Experimental Loss to Convergence Loss, Dimensionless
1.8×10^{-3}	A	540	118	422	4.58
	B	0	98.8	− 98.8	0
	C	−180	84.1	−264	−2.14
	G	5620	260	5360	21.6
	F	2100	335	1765	6.27
0.6×10^{-3}	A	80	39.4	40.6	2.03
	B	− 37	33.0	− 70	−1.12
	C	− 84	28.1	112	−2.99
	G	746	86.8	659	8.59
	F	372	112	260	3.32

It may be regrettable that some of the experimental flow rates were rapid enough to permit partly turbulent flow in the sand just outside the slots, even though the flow was wholly viscous in the main sand body for all test rates. However, the formation of a sand bridge that causes an effective posi-

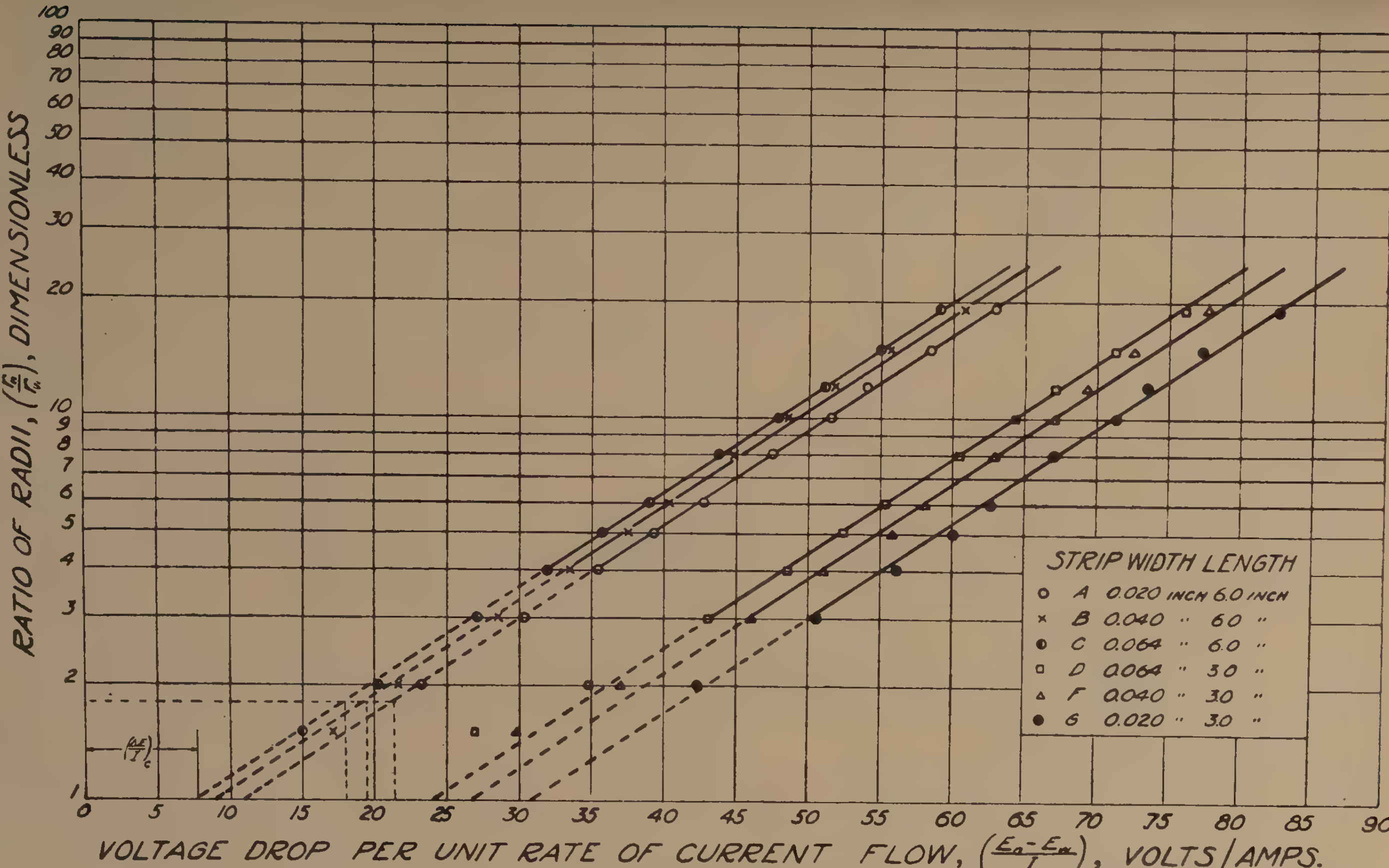

FIG. 7.—ELECTRICAL ANALOGY CURVES SHOWING VOLTAGE DROP PER AMPERE IN VICINITY OF "WELL" WALL FOR DIFFERENT COPPER STRIPS.

tive pressure loss probably would induce turbulence at lower rates because of the unusually tight packing of the sand grains at the bridge. Computations showed that the turbulence in the sand just outside the slots did not become fully developed at any of the test rates. Nevertheless, the experimental total-pressure losses determined with the fluid-flow apparatus are somewhat greater than would be expected in the field under similar conditions if the flow is assumed to be wholly viscous in the sand in the immediate vicinity of the liner wall of a producing oil well.

According to Coberly's rule,[4] a slot with a width equal to twice the grain size at the 10 percentile (obtained from sieve-analysis curve) of the sand will prevent entry of sand into a well. Apparently no stable bridge would be formed if a wider slot were used. The 10-percentile size of the test sand used in the experiments reported herein was 0.0165 in., so that the widest slot that would prevent entry of sand into the experimental well apparently would be 0.033 in. The widest slots used in the foregoing reported tests were 0.032 in. (slots *B* and *C*). An attempt was made to test a slot 0.040 in. wide with the same sand, but this slot would not hold back the sand.

The negative experimental losses given in Table 2 for slots *B* and *C* suggest that the permeability of the sand just outside these slots probably was increased during formation of the sand bridge, hence it may be concluded that the total pressure loss resulting from the use of a slot having a width equivalent to at least the sand grain size at the 10 percentile is small, nil, or negative, regardless of the rate of flow.

Other results presented in Table 2 show that the additional pressure loss due to bridging increases as the slot width decreases for slots of the same length.

A study of the experimental electrical and fluid-flow systems reveals that the outer limit of the region of slot (or copper strip) influence is indicated in any particular test by the abscissa of the point at which experimental data begin to deviate appreciably from the respective straight line in Figs. 5, 6 or 7, representing radial flow. As the experimental data do not deviate appreciably from any of the straight lines of these figures until $\left(\frac{r_n}{r_w}\right)$ is at least less than 3, the flow disturbance in the sand (or electrolyte) caused by any of the slots or copper strips was within an annular space defined by the wall of the well and an imaginary cylinder having a radius equal to three times the well radius and its axis coincident with the well axis.

Conclusions

This paper represents the results of an experimental investigation designed to determine the effect of the sizes of certain rectangular slots used in a slotted liner on the pressure gradient in the vicinity of the wall of a producing oil well. Attention was directed to a study of the flow conditions about a single slot in each test as the flow conditions about all other slots of a liner were assumed to be similar. The most pertinent results of the investigation follow:

1. The additional pressure loss resulting from the formation of a sand bridge over a rectangular slot becomes small, nil, or even negative if the slot width used is equivalent to at least twice the grain size at the 10-percentile size of the sand, taken from its sieve-analysis curve. The pressure loss resulting from the bridge increases markedly when the slot width is reduced.

2. The additional pressure loss resulting from the convergence or crowding of the streamlines in the sand near a slot decreases as the slot length is increased. Experimental results show that the additional pressure drop per unit rate of flow due to a slot of length equal to the sand thickness is about one-third the loss for a slot of the same width but only one-half the length, placed so that its center is midway between the upper and lower horizons defining the oil-

bearing sand, if the effect of bridging is neglected. Increasing the width of the slots without increasing the length does not reduce the convergence loss greatly.

3. The pressure loss due to the slots alone, which is similar to the pressure drop across an orifice in pipe-line flow of fluids, is small compared with the corresponding loss that would occur in the sand near the slot.

4. A slotted liner does not affect normal flow conditions in the sand beyond a distance, measured from the well axis, of three times the well radius.

5. The apparatus and experimental technic described in this report would be adaptable to further studies pertaining to the effect of a slotted or other type of perforated liner on the pressure gradient in the vicinity of the wall of a producing oil well.

Acknowledgments

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Capillary Behavior in Porous Solids

By M. C. Leverett,* Member A.I.M.E.

(Tulsa Meeting, October 1940)

Knowledge of the theory underlying the behavior of mixtures of fluids in reservoir rocks is essential to the proper solution of certain types of problems in petroleum production, but is as yet incompletely developed. The object of this paper is to show the application of well established thermodynamic and physical principles to these problems, and thus to assist in the development of the basic theory. For convenience the problems to be considered here may be divided into two groups:

1. Static problems, involving only the static balance between capillary forces and those due to the difference in densities of the fluids; i.e., gravitational forces.

2. Dynamic problems, involving analysis of the motion of mixtures of immiscible fluids in porous media under the influence of forces due to gravity, capillarity, and an impressed external pressure differential.

Capillary Equilibrium in Sands

Under this heading the static type of problem will be discussed and the results of experimental investigations on the capillary properties of unconsolidated sands will be presented. Although the discussion of this section is, in a sense, prefatory to the treatment of problems of mixture flow, the concepts developed here have considerable intrinsic importance apart from their application to flow problems. For, it is reasonable to postulate that the reservoir fluids are, owing to their long existence in undisturbed mutual contact prior to exploitation, in substantial equilibrium. It follows that their distribution in the reservoir at the time of tapping should be entirely predictable from the theory of capillary equilibrium, provided certain experimentally measurable properties of the reservoir rock are known. Knowledge of the distribution of the several fluids in the reservoir is, of course, helpful in the estimation of reserves and in other problems.

It is to be emphasized that throughout the discussion of capillary statics it is assumed that the fluids are in equilibrium from the capillary standpoint. Thus, water, where it is referred to as being in a reservoir, will be understood to be interstitial water, present at the time of drilling the reservoir, commonly termed "connate" water.

The theory developed here is perfectly general for any porous solid, whether a carefully prepared unconsolidated sand or a natural sandstone from an oil reservoir. At present, however, only problems involving clean, unconsolidated sands can be made to yield numerical solutions, since only such sands have been adequately investigated experimentally. Experimental evaluation of the pertinent properties of natural reservoir rocks will permit the extension of the numerical treatment to problems involving these materials. We shall now consider in some detail the static equilibrium of fluid mixtures in porous solids; that is, the manner in which the reservoir fluids are distributed vertically when the forces due to capillarity are just balanced by those due to gravitation.

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Interfacial Curvature and Capillary Pressure

Although it is not infrequently assumed that sands may be represented as behaving like a bundle of straight, cylindrical capillary tubes, this analogy is in many respects an unwarrantable and misleading simplification. It is necessary for the purpose of this discussion to discard this concept and substitute a more realistic one.

Simple visual examination of a porous material, in the pore space of which a mixture of two fluids exists, shows that the *interfacial boundary between the fluids is curved*, and that the sharpness of the curvature depends on the size of the intergrain spaces and the proportions of the fluids present. It is well established that the cause of this curvature is the interfacial tension between the fluids; the physical law determining the shape of the interfacial surface is that the interfacial-surface free energy shall be the minimum compatible with the volumes of fluids present and the shapes of the restraining solid surfaces. The view here taken is that this *interfacial curvature is the most significant property of the system from the standpoint of capillary behavior.*

The curvature of the interfacial surface gives rise to a pressure differential across the interface, which here will be termed the "capillary pressure." When fluids flow under the action of capillarity, the driving force causing flow is this capillary pressure; it is thus of the first importance in problems of capillary flow. The capillary pressure is related to the curvature of the interface by the well-known expression[1] due to Plateau:

$$P_c = \gamma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) \qquad [1]$$

where P_c is the capillary pressure, γ is the interfacial tension or unit free surface energy, and R_1 and R_2 are the principal radii of curvature of the surface. The expression $\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$ is defined as the *mean curvature* of the surface and will be represented by C. Fig. 1 shows the approximate shape of

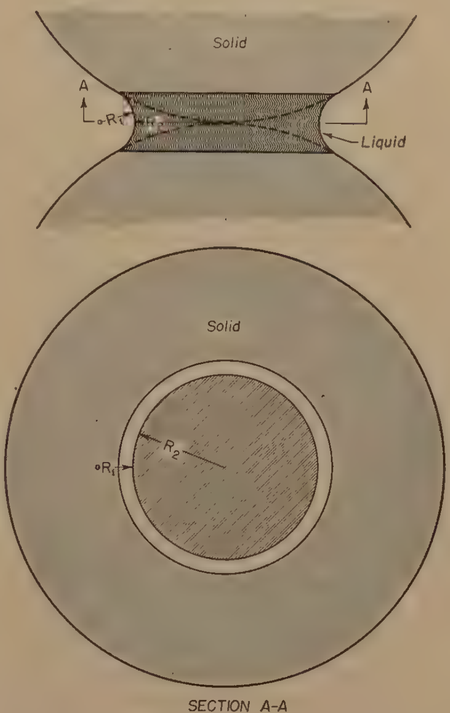

Fig. 1.—Accumulation of liquid at contact point between spherical grains.
R_1 rotates in plane of paper in upper view, R_2 rotates in plane of paper in lower view.

the oil-water interface when only a small amount of water is present between two spherical grains. The radii of curvature, R_1 and R_2, are vector quantities and hence have direction as well as magnitude. If both radii have their centers of rotation on the same side of the interface in question, both radii have the same sign. But if the centers of rotation are on opposite sides of the interface, one radius is positive and the other negative in sign. The latter situation prevails in Fig. 1. It makes no difference which of the two radii R_1 and R_2 is called positive or negative as long as the same con-

[1] References are at the end of the paper.

vention is used throughout. In order to be consistent with our later definition of P_c, we shall say here, arbitrarily, that in Fig. 1 R_1 is positive but R_2 is negative. That is, in general if the center of rotation of a radius of curvature lies on the side of the interface occupied by the fluid which preferentially wets the solid, that radius will be given a negative sign. If the center of rotation lies on the side of the non-wetting fluid, the radius will be given a positive sign. As drawn in Fig. 1, R_2 is numerically greater than R_1, so that the mean curvature of the interface, $\left(\frac{1}{R_1} + \frac{1}{R_2}\right)$, is positive even though $\frac{1}{R_2}$ is a negative number. In general, the water-oil, or water-gas, interface will have a positive curvature whenever the water tends to be imbibed by capillarity.

Interfacial Curvature and Height

In a petroleum reservoir rock, interstitial water coexists with the oil at all levels throughout the entire reservoir and, as stated above, we shall assume that these fluids are initially in substantial capillary equilibrium. Where the interfacial tension is constant throughout the reservoir, a well-known relation exists among the capillary pressure across a given interface, its mean curvature, and its vertical position in the reservoir.

In order to derive this relation, let us consider a large porous mass, preferentially wetted by water, in which two fluids, such as oil and water, are distributed in the manner required for capillary equilibrium. Let us suppose that a very small volume of water, ΔV, is to be transferred from the level h in the sand to the level $h + dh$. Since, by assumption, capillary equilibrium exists in the sand the free energy change dF (i.e., the isothermal reversible work possible to get out of the transfer) is zero; $dF = 0$. However, the total change in free energy, dF, accompanying this transfer is the sum of two parts:

1. The partial change of free energy of the water element in rising a distance dh in a gravitational field, which is given by

$$\left(\frac{\delta F}{\delta h}\right) = \rho_w g \Delta V$$

where the element has the volume ΔV.

2. The partial change of free energy of the water element in passing from a level h where the pressure in the water is P_w to a level $(h + dh)$ where the pressure in the water is $(P_w + dP_w)$. This is given by

$$\left(\frac{\delta F}{\delta P_w}\right) = \Delta V$$

The total change in free energy is the sum of these two, whence we may write immediately

$$dF = \left(\frac{\delta F}{\delta h}\right) dh + \left(\frac{\delta F}{\delta P_w}\right) dP_w = \rho_w g \Delta dh + \Delta V dP_w = 0 \quad [2]$$

or

$$-dP_w = \rho_w g dh \quad [2a]$$

in which ρ_w is the density of the water, and g is the acceleration due to gravity.

A similar derivation may be made for any other fluid present at equilibrium, with an exactly similar result regardless of the nature of the fluid. If, in the case under discussion, the second fluid is oil, the equation corresponding to eq. 2*a* is

$$-dP_o = \rho_o g dh \quad [2b]$$

(The subscripts *o* and *w* will be used to indicate oil and water respectively.)

In accordance with our convention regarding the sign of the mean interfacial curvature, P_c, the capillary pressure across the water-oil interface is, by definition, $P_c = P_o - P_w$, whence, differentiating,

$$dP_c = dP_o - dP_w$$

Combination of this expression with eqs. 2*a* and 2*b* yields

$$dP_c = \Delta\rho_{wo} g dh \quad [2c]$$

where $\Delta\rho_{wo}$ represents the difference in densities between the water and oil.

When the capillary pressure P_c is zero, the interface has zero curvature, and hence is in equilibrium with a flat interface (a "free liquid surface") at its own level and external pressure. However, as will be observed below, there is a limit to the smallness of the interfacial curvature that may possibly exist in a column of sand of definite properties. For this reason there is no interface in the system across which the pressure differential is zero. We may, however, calculate for any equilibrium surface of known curvature how far below that surface the hypothetical free liquid surface is, and it will be convenient to call $h = 0$ at this level, since at this level the capillary pressure is likewise zero. In an oil-water-sand system, the hypothetical free liquid surface is always below the lowest level at which oil is found if the oil is less dense than the water. Therefore, calling $h = 0$ at the level at which the surface, if it actually existed, would have zero curvature, eq. 2*c* becomes, on integrating between limits and recalling eq. 1,

$$P_c = \Delta\rho_{av.}gh = \gamma\left(\frac{1}{R_1} + \frac{1}{R_2}\right) = \gamma C \quad [2d]$$

where h is the vertical distance of the interface in question above the free liquid surface. As indicated in eq. 2*d*, the average value of the density difference $\Delta\rho_{av.}$ must be used in the integrated form if this difference varies significantly with height.

It should be remarked that the free liquid surface is not always hypothetical. For example, where water is being imbibed from an open dish into a sand column standing in an air-filled room, the free liquid surface is real, and is the water-air interface in the dish.

It is to be emphasized that eq. 2*d* was derived without any assumptions regarding the fluids or system, except that they are isothermal and in capillary equilibrium. It applies equally well to water-air, water-oil, or oil-gas systems, and the solid phase may have any properties whatever. A corollary of eq. 2*d* is that all interfaces in any particular two-fluid system have the same curvature and capillary pressure at the same horizontal level.

Approximate Magnitude of Capillary Pressures in Oil Sands

Eq. 2*d* is a direct means of estimating the maximum differences in capillary pressure that may exist in a virgin reservoir. For example, in an oil sand 100 ft. thick, in which the average difference in specific gravities of oil and water is 0.3, the capillary pressure at the top of the sand is about 13 lb. per sq. in. greater than at the bottom of the oil zone. The capillary pressure at the bottom of the oil zone depends on the minimum curvature that may exist in the sand, and hence varies widely depending on the texture of the sand. Nevertheless, it seems unlikely that original capillary pressures greater than a few times the value in the above illustration will be encountered frequently. Although, as in this example, the pressures due to capillarity may be of fairly large size, it must be realized that at equilibrium they are exactly balanced by the differences in gravitational forces on the two fluids. It is only when this balance is disturbed that part of the capillary pressure becomes available to cause flow of fluids.

Eq. 2*d* likewise permits estimation of the mean curvature of the capillary surface at any height if the interfacial tension is known. In the example above the mean curvature at the top of the oil zone is (assuming it to be comparatively small at the bottom of the oil zone) about 65,000 in.$^{-1}$ (25,000 cm.$^{-1}$) if the interfacial tension is 35 dynes per centimeter.

Relation between Interfacial Curvature and Saturation

Since eq. 2*d* relates curvature and height, a relation between curvature and saturation (fraction of voids occupied by a given fluid) would suffice to determine, for given values of the density difference and inter-

facial tension, the height-saturation diagram; i.e., the vertical distribution of the fluids. It is apparent from this that the *curvature-saturation function is the fundamental relation* necessary for solution of problems of static capillarity in sands.

Quite apart from its thermodynamic relation to capillary pressure and height, the curvature of the oil-water interface is a geometric quantity determined by the dimensions of the interstice in which it exists and by the proportions of the fluid phases present. There is thus the theoretical possibility of determining mathematically the mean curvature corresponding to a given water saturation in an interstice of given dimensions. However, analytical attempts to evaluate the curvature-saturation function have failed in all except highly oversimplified cases. For example, the problem has been attacked by Smith and others[2–7] for regularly packed spheres. In actual sands or sandstones the extreme irregularity of the intergrain spaces prohibits analytical treatment. Some characteristics of the saturation-curvature function, however, may be determined without recourse to extensive experiments, and these will be discussed briefly before proceeding to the experimental evaluation of the function.

It is evident from Fig. 1 that changes in water saturation in a pore of any shape whatever result, in general, in curvature changes at the water-oil interface. It is likewise true that there is a lower limit, greater than zero, to the curvature that may exist in a column of sand of definite properties, although this fact is not readily deducible from purely geometric considerations. Rather, it is demonstrable by the simple experimental observation that in sand columns containing two fluids in equilibrium it is well known that substantially complete water saturation prevails up to a definite distance above the free water surface. Again, the simple fact that a solid imbibes a liquid to near-saturation shows that there is no interfacial configuration of zero curvature typical of any saturation (less than unity) in the sand.

Smith,[5,6] Keen,[7] Versluys[8] and others have pointed out that there are three general types of occurrence of water, or regions of water saturation in a porous solid:

1. Saturation region. Complete water saturation.

2. Pendular region. Lowest water-saturation range. Water occurs as pendular rings around grain-to-grain contacts. The solid, where not covered by water in the pendular rings, is covered with a very thin film of water if the contact angle[9] is zero,* or by oil if not. Fig. 2*a* illustrates this saturation region.

3. Funicular region. Intermediate water saturation. Addition of water to the pendular rings of Fig. 2*a* causes them to grow and soon they become so large that they touch each other at their edges and merge. This state of coalesced rings is indicated in Fig. 2*b*. Addition of still more water causes complete coalescence of the funicular rings, the result being a web of water across the interspace between three or more grains. Both of these configurations are included in the funicular saturation region, since in either case it is possible to pass from any position in one fluid to any other in the same fluid by a tortuous, cordlike (funicular) path through that fluid.

The nomenclature is that used by Versluys.[8]

Saturation Hysteresis

Previous work in this field[2–7] has shown also that the curvature-saturation function is not single valued over its entire range;

* It is believed that the contact angle in natural petroleum reservoirs is substantially zero, with few exceptions; this view is based on a considerable amount of evidence which, if not rigorously conclusive, is strongly presumptive. It may be pointed out that the thermodynamic discussion presented here is valid regardless of the magnitude or existence of the contact angle; if the contact angle is not zero some changes in the numerical values of the curvature-saturation relation and permeability-saturation curves must be made, but these changes are in predictable directions. In the experimental work described in the following pages undoubtedly the contact angle was zero.

there is a considerable hysteresis loop in the function. The reasons for this behavior are derivable from the geometry of the system, and have been discussed in detail by Smith,[6] who shows that there is a large variety of configurations that may stably correspond to a given average water saturation. This is particularly true of the funicular region of saturations.

Aside from this ambiguity in the curvature-saturation relation, which is probably often unimportant, we may regard the curvature-saturation function as characterizing the sand to which it applies. This view obviates any necessity for inventing fictions about the sand, such as a suppositious distribution of "pore sizes" of "equivalent circular section." The latter concept in particular is likely to be misleading, since the same intergrain space is capable of behaving as though possessed of many different such sizes. It is sufficient to state, first, that the intergrain spaces, the pores, are in fact of various dimensions, and, second, that any such space may contain in it a capillary surface having a curvature larger than a definite minimum. Thus the sand has a characteristic distribution of interfacial curvatures with respect to saturation.

Displacement Pressure

It may be noted in passing that the capillary pressure existing at the maximum position of the top of the saturation zone in a vertical sand column is numerically the "displacement pressure,"[10] since it is the minimum pressure differential that suffices to displace water from the water-saturated sand.

Experimental Evaluation of Curvature-saturation Function

The attempts of Smith and others to evaluate analytically the curvature-saturation function have been mentioned previously. The results of this work give curvature-saturation plots that undoubtedly are of the proper form and hence are of value but which cannot be applied quantitatively to real sands or sandstones. Therefore this function has been investigated experimentally in the present research.

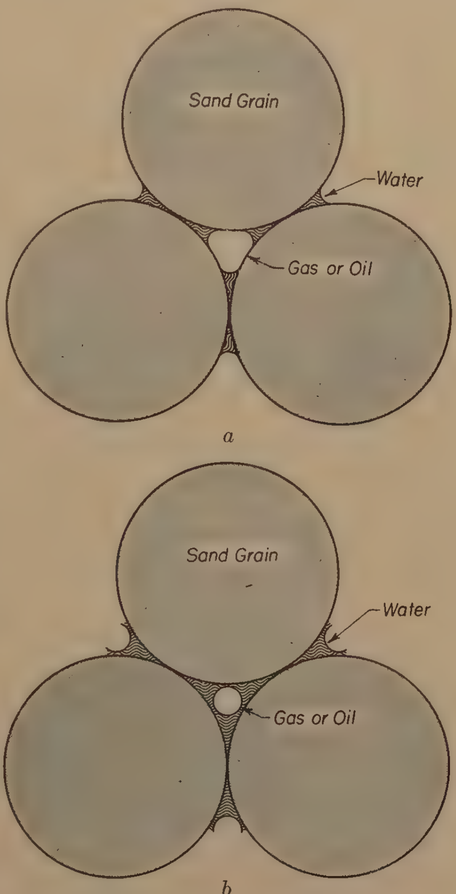

FIG. 2.—SATURATION RINGS.
a. Pendular saturation rings.
b. Funicular saturation region, water existing as coalesced rings.

Of the various theoretically possible techniques for evaluating this function, the height-saturation method was chosen. Essentially, this comprises letting water and air come to capillary equilibrium in a vertical sand column, and measuring the resultant water saturations at a number of heights. Similar work by King,[11] Haynes

and Keen[7] and Smith[4-6] has been reported, but these experiments were incomplete because the permeabilities, and in some cases other properties of the system, were not measured.

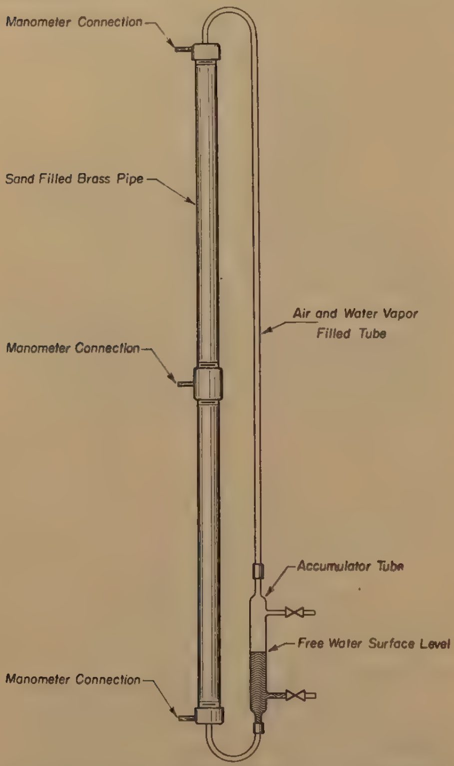

FIG. 3.—BRASS APPARATUS FOR DETERMINING CAPILLARY EQUILIBRIUM OF WATER DISTRIBUTION IN UNCONSOLIDATED SAND.

Two very similar procedures were used in the present study. The first comprised packing sand in vertical glass tubes and measuring its porosity and permeability to both water and air where possible. (The manometer taps, used during permeability measurements, were closed while the system came to equilibrium.) The tubes were about ¾ in. in diameter and up to 10 ft. long. Two such tubes were packed with each sand used. One tube of each pair was saturated with water, which was then allowed to drain from the sand into the accumulator tube (Fig. 3). The water level in the accumulator tube was kept constant by removing water as it drained. The other tube of each pair was initially dry; water was fed to the accumulator tube as fast as the sand imbibed it. Equilibrium was thus approached from both directions and the maximum extent of the hysteresis zone defined. The saturation changes in the sands were followed by means of the conductometric technique previously described,[12,13] metallic screens at top and bottom of the columns serving as electrodes by which to introduce the alternating current. The electrical potential drop along the sand column was measured at 6-in. intervals by means of stiff wires sealed through the side of the glass column. Because of its fragility, this apparatus was later replaced by the one sketched in Fig. 3, where a brass tube replaces the glass one. At the end of the run the brass tubing was cut into 10-cm. sections and the water content of the sand in each section determined gravimetrically. With either apparatus it was found that very little change in distribution of water took place after about two weeks (imbibition and drainage rates were followed, for the brass apparatus, to gauge the progress of the experiment); however, the experiments usually ran several times that length of time.

In all, four previously sized and ignited sands and two that contained clayey material were thus studied. Of the clayey sands, one was a clean ignited sand to which 5 per cent by weight of Drilloid (a bentonitic drilling-mud addition agent) was added, and the other was a naturally occurring surface sand (Queen City, Texas, formation). Table 1 summarizes the properties of the systems investigated by both techniques.

Results of Height-saturation Experiments

When the results of these experiments were plotted (Fig. 4) in dimensionless form as

$$\frac{\Delta\rho g h}{\gamma}\sqrt{\frac{K}{\phi}} \text{ against } S_w$$

it was found that the data for the four clean sands fell satisfactorily near two curves, one for imbibition of water and the other for drainage. K is the permeability of the sand to a homogeneous fluid, expressed in units consistent with the other variables in the group, and ϕ is the fractional porosity of the sand. The form of this correlation may be derived from either of two assumptions: saturation, a definite fraction of the total surface of the sand itself.[14]

It is believed that the nearly vertical trend of the drainage data at low water saturations in Fig. 4 represents a relatively poor approach to equilibrium, caused by the low permeability to water in this saturation region. This view is substantiated by the results of an experiment on the capillary depression of mercury in an "air-wetted" sand (the mercury-air-sand contact angle was probably near 140°). Because of

TABLE 1.—*Properties of Systems Used in Height-saturation Experiments*

Sand No.	I		II		III		IV		V		VI	
Screen analysis	100–200 Mesh Plus 5 Per Cent by Wt. Drilloid		200–325 Mesh		80–100 Mesh		50 Per Cent 100–200 Mesh 50 Per Cent 200–325 Mesh		100–200 Mesh		Queen City Sand[a]	
Type experiment	Drainage	Imbibition	Drainage	Imbibition	Drainage	Imbibition	Drainage	Imbibition	Drainage	Imbibition	Drainage	Imbibition
Permeability to air, darcys:												
Top half column	1.80	2.43	3.17	3.29	17.1	17.5	2.20	2.72	3.50	3.27	0.650	0.731
Bottom half column	2.14	2.30	3.19	3.77	17.3	17.5	2.52	2.72	3.76	3.76	0.750	0.830
Average	1.97	2.37	3.18	3.53	17.2	17.5	2.36	2.72	3.63	3.52	0.700	0.781
Permeability to water, darcys:												
Top half column	0.328						2.48		3.60		0.119	
Bottom half column	0.234						2.48		3.60		0.025	
Average	0.282						2.48		3.60		0.072	
Average porosity, per cent	40.8	41.5	46.1	46.4	39.1	39.0	48.2	49.1	39.5	39.4	38.2	39.4
Interfacial tension, dynes per cm	70	53	70	73	70	69	70	60	70	49	70	62
Duration of experiment, days	75	76	30	30	30	30	83	43	78	79	70	74

[a] Screen analysis:

	Per Cent by Wt.
−100 mesh	>0.1
100–200	5.9
200–325	85.6
325+	8.5
	100.0
Porosity in situ	43 8

1. That the height at which a definite water saturation is found at equilibrium is inversely proportional to an "equivalent circular diameter" of the voids in the sand[12] calculated from its porosity and permeability, inversely proportional to the density difference and directly proportional to the interfacial tension.

2. That the interfacial surface area between the two fluids is, at a given water

the low viscosity of air compared to that of water, a much accelerated approach to equilibrium was attained. The broken portions of the curves of Fig. 4 represent a reasonable estimate of water distribution in the low saturation region, based on Smith's theoretical work and the mercury-sand-air experiment.

The ordinate of Figs. 4 and 5 is, referring to eq. 2*d*,

$$\frac{\Delta\rho gh}{\gamma}\sqrt{\frac{K}{\phi}} = C\sqrt{\frac{K}{\phi}}$$

Evidently the group

$$\frac{\Delta\rho gh}{\gamma}\sqrt{\frac{K}{\phi}}$$

is interfacial curvature multiplied by a factor that is a property of the sand alone. Hence the curves of Fig. 4 may be regarded as generalized curvature-saturation plots, applicable to all clean unconsolidated sands.

Where, as in the imbibition experiments, water advances into the sand, displacing, for example, air, it is invariably found that the water does not completely displace the air from the sand. Part of the air remains apparently trapped in what would otherwise be a region of 100 per cent water saturation. Microscopic examination shows this residual air to exist as globules surrounded by water. It is thus unable to escape by ordinary flow. From Smith's work,[6] it appears highly probable that such residual globules are thermodynamically unstable; it is believed that they tend to disappear by solution in the water and subsequent diffusion to more stable positions. This behavior has been observed experimentally in one case in the present research, and is believed to have been typical of all the cases studied, although perhaps too slow to attract notice in any but the one instance mentioned. The lower curve of Fig. 4 has been drawn in accordance with this view.

The experimental results (Fig. 4) demonstrate that clean sands of low permeability retain more water at a given height than more permeable ones. The hysteresis zone is clearly evident in Fig. 4, but it is seen to be of limited vertical extent. Hence, although it is difficult to state from the results obtained the saturation corresponding to a curvature falling in the hysteresis zone, the curvature corresponding to a given water saturation can be estimated with relatively small error.

Clayey Sands

The data for clayey sand do not correlate on the basis of Fig. 4. The results, plotted in Fig. 5, show that more water was retained at large values of h, the height, and less at small ones than the clean-sand correlation predicts. Use of the permeability of the water-saturated sand to water for K in the ordinate did not improve the correlation.

These results are explainable by the fact that clays and shales sorb water, the water so taken up being held more tightly than the same amount of water would be held by capillarity. The amount of so-called "hydratable" material in natural sandstones is thus important, since, as these data show, it affects strongly the curvature-saturation function. The large "connate" water saturations of some reservoir rocks therefore may be attributable to the presence of "hydratable" solids mixed with the sands. The lower permeability of clayey or shaly sands to water than to dry air is probably explained by the swelling of these "hydratable" materials in water, which reduces the effective size of the flow passages.

Capillary Thermodynamics in Two-fluid Systems

Some of the thermodynamic properties of two-fluid mixtures in porous solids are of particular interest, among them the free surface energy.

Let us consider an element of sand containing, for example, only water and oil, and suppose that there is, at the same horizontal level, a water reservoir, which has a surface of zero curvature, and that both sand and water reservoir are enclosed in an otherwise oil-filled space. Evidently, the pressure in the water in the sand (because it is bounded by a curved surface) is less than that in the water reservoir (the two are not assumed to be in equilibrium), and it is readily shown that this pressure deficiency is P_c, the capillary pressure, in the

sand. For the water, the partial change of free energy with pressure is

$$\left(\frac{\delta F}{\delta P}\right) = V$$

or, since water is substantially incompressible

$$F_2 - F_1 = V(P_2 - P_1) \qquad [3]$$

whence the difference in free energy per unit volume of water in the external reservoir, F_2, and in the sand, F_1, is

$$F_2 - F_1 = P_2 - P_1 = P_c \qquad [4]$$

Since P_c is the free energy increase (the isothermal, reversible, work necessary) accompanying the transfer of unit volume of

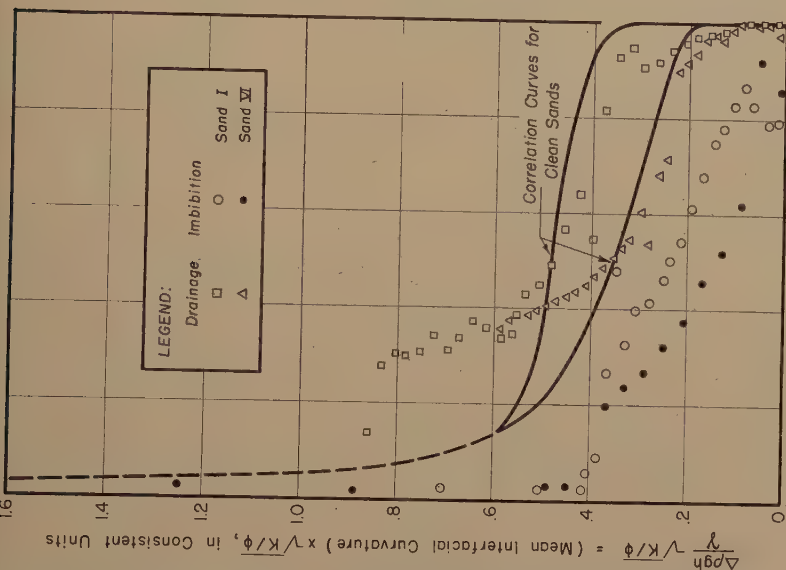

FIG. 5.—DATA FROM HEIGHT-SATURATION EXPERIMENTS ON CLAYEY SANDS, SHOWING DEVIATION FROM CLEAN SANDS.

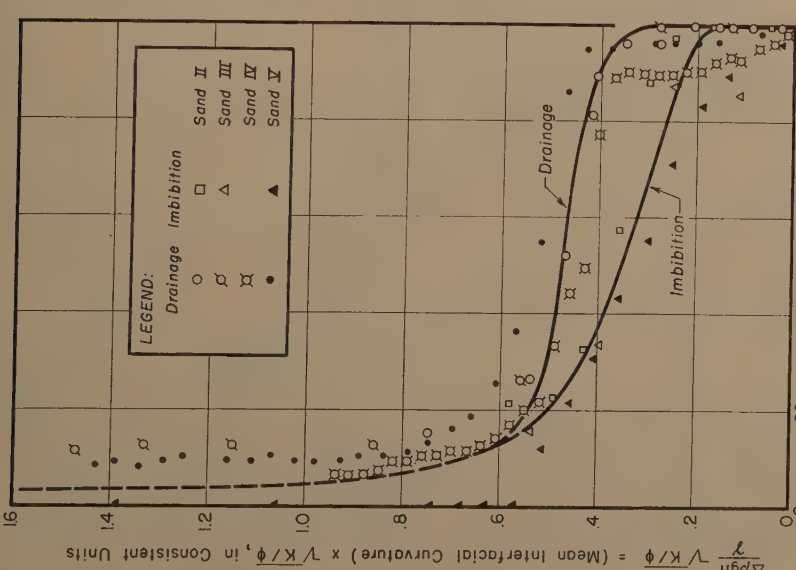

FIG. 4.—CORRELATION OF DATA FROM HEIGHT-SATURATION EXPERIMENTS ON CLEAN UNCONSOLIDATED SANDS.

water from the sand to the zero curvature reservoir at the same level, we may consider that

$$P_c = \left(\frac{\delta F}{\delta V}\right) \quad [5]$$

where V represents the volume of water transferred out of the sand. It is evident from this that the negative capillary pressure, $-P_c$, is the partial free energy per unit volume of water in the sand with respect to that of water at the same level and external pressure, but bounded by a zero curvature interface. Thus viewed, the capillary pressure is clearly a close analog to the "partial free energy" of Lewis and Randall[15] and to the "chemical potential" of Gibbs.[16] For this reason some authors have called P_c the "capillary potential."[17,18]

If, arbitrarily, the element of sand is so chosen that it has unit volume of pore space, it is evident that the volume of water in it and its fractional water saturation are numerically equal, and $dV = -dS_w$, since V represents water transferred *out* of the sand. Substitution in eq. 5 and rearrangement gives

$$dF = -P_c dS_w \quad [6]$$

where dF is now the increase in free energy of the water per unit of pore space when the water saturation is changed by the amount dS_w. The reversible work necessary to decrease the water saturation by a differential amount is quantitatively converted into free surface energy, whence dF must also be the increase in free surface energy.

The difference in free surface energies between two saturation states in the same sand, therefore, is, per unit of pore volume,

$$\Delta F = -\int_{S_{w_1}}^{S_{w_2}} P_c dS_w \quad [7]$$

This integral is the area under the capillary pressure-saturation curve and may be determined graphically.

Although, in the foregoing derivation, it has been assumed that only water and oil were present, a completely similar result is obtained for water-gas or oil-gas systems.

Eq. 7 is rigorous as derived, but its numerical evaluation necessarily assumes that P_c, capillary pressure, and S_w, water saturation, are uniquely related. Inasmuch as saturation hysteresis exists, this is only approximately true, and some uncertainty is thus inherent in this manner of evaluating the free surface energy.

Extent of Interfacial Fluid: Fluid Surface

The surface tension γ is by definition the unit free surface energy

$$\left(\frac{\delta F}{\delta \sigma}\right) = \gamma \qquad \text{or} \qquad \frac{dF}{\gamma} = d\sigma$$

where σ will be defined as the two-fluid interfacial surface area per unit of pore volume. If all the change in free surface energy is due to areal changes in the fluid:fluid interface, it is evident that the difference in interfacial surface areas between two saturation states results from dividing eq. 7 by γ, the interfacial tension:

$$\sigma_2 - \sigma_1 = \frac{F_2 - F_1}{\gamma} = -\frac{1}{\gamma}\int_{S_{w_1}}^{S_{w_2}} P_c dS_w \quad [8]$$

It is important to note, however, that two kinds of interfacial surface exist in the sand:

1. Water-oil (or water-gas). The unit free surface energy of this surface is γ, the interfacial tension.

2. Solid-liquid; either sand-water or sand-oil. The unit free surface energy of these surfaces is not known, and undoubtedly is different for the sand-water and the sand-oil interfaces.

Eq. 8, therefore, is valid only if the amounts of sand-oil and sand-water interfaces are constant over the range of saturations S_{w_1} to S_{w_2}. This condition definitely does not prevail in the pendular region of saturations, and possibly does not obtain in certain parts of the funicular region. Eq. 8 therefore is inapplicable for relatively low water saturations, but probably may be

applied where water saturations of 25 per cent or more are involved.

If, in the integration of eq. 8, S_{w_1} is chosen equal to unity (100 per cent water saturation), the integral gives the total two-fluid interfacial surface at S_{w_2}, since at 100 per cent water saturation there is obviously no two-fluid interface in the sand. Fig. 7 shows, as an example, the results of the graphical integration of the capillary pressure-saturation curves of Fig. 6. Although, because of the existence of saturation hysteresis, significantly different results for the extent of the two-fluid inter-

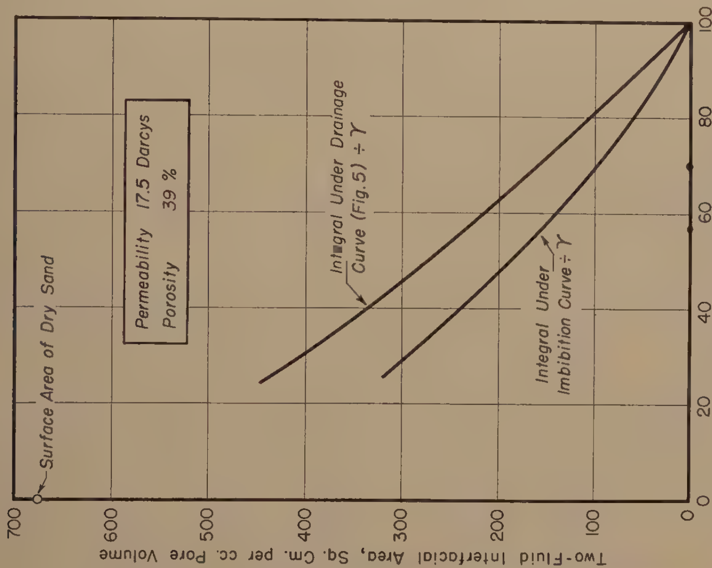

FIG. 7.—TWO-FLUID INTERFACIAL SURFACE AS FUNCTION OF WATER SATURATION IN UNCONSOLIDATED SAND.

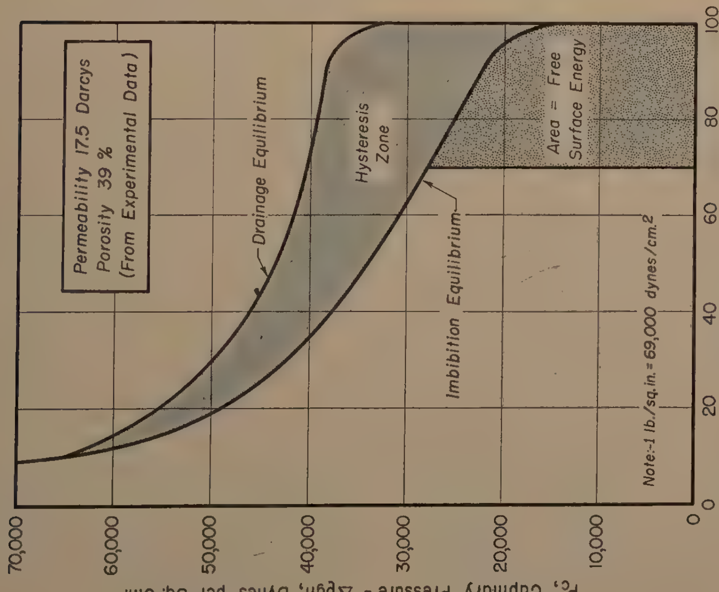

FIG. 6.—EQUILIBRIUM DISTRIBUTION OF AIR AND WATER IN UNIFORM UNCONSOLIDATED SAND, PERMEABILITY 17.5 DARCYS.

face are obtained from the curves of Fig. 7, the order of magnitude of this area is well defined. Also shown on Fig. 7 is the surface area of the dry sand, computed by the method of Carman.[14] The two-fluid interfacial area is seen to be less than that of the sand itself over the region of application of eq. 8.

Occasionally, it will be necessary to choose between the curvature-saturation data as obtained by imbibition and drainage experiments. In this connection it is helpful to note that since the states in the hysteresis zone persist indefinitely if undisturbed, but are permanently altered if a small but finite disturbance occurs in the system, these states represent *metastable equilibria.* It appears likely that the conditions under which hydrocarbons accumulate in and are produced from the earth will lead to distributions of the fluids corresponding more closely to the imbibition equilibrium than to the drainage equilibrium. Where, therefore, it is necessary to choose between the two sets of data we shall use the lower. Computations made for this paper are on this basis.

Equilibrium Distribution of Three Fluids in Sands

Although only two-fluid systems have so far been discussed, an analogous treatment of three fluids may be made. It may be shown that eq. *2d* applies equally well to the oil-water, oil-gas, and water-gas interfaces; when so applied the physical constants appearing in it must, of course, be those for the two fluids bounding the interface under question. Since the interfacial curvature is fixed (within the limits of saturation hysteresis) by the geometry of the system, as pointed out above, it is reasonable to assume that the relation between total liquid saturation and interfacial curvature at the gas-liquid interface is independent of the number or proportions of the liquids which, together, comprise the total liquid saturation.* This assumption fixes the slope (at a given total liquid saturation) of the total liquid saturation versus height curve for fluids of definite densities and interfacial tensions. The vertical position of the $(S_o + S_w)$ (total liquid) curve is fixed by the amount of oil present.

In order to illustrate the application of these principles to the determination of the original fluid distribution within a reservoir, the distribution of gas, oil, and water at equilibrium has been calculated for a clean, uniform, unconsolidated sand containing a relatively small amount of oil. The conditions assumed were as follows: oil-water, gas-oil, and water-gas interfacial tensions: 35, 20, and 65 dynes per centimeter, respectively; specific gravities oil, water, and gas: 0.7, 1.0, and 0.1 respectively; sand permeability: 1 darcy; porosity: 35 per cent; total thickness of oil interval: 8.5 feet.

The results of these computations are shown in Fig. 8, from which it may be observed that the vertical transition from gas to oil is sharper than that from oil to water, but that both the gas-oil and water-oil contacts are zones of rapid transition from a region saturated primarily with one fluid to a region saturated primarily with the second fluid, rather than levels of saturation discontinuities. The thickness of the transition zones depends upon the amounts of the fluids present and upon the character of the fluids and of the reservoir rock. It is interesting to observe that these calculations indicate that some oil may be contained in portions of the sand that may be expected from their saturations to produce only gas or water, an observation that has been confirmed by analyses of cores taken from above the "gas-oil contact" and below the "water-oil contact" in producing oil fields. It should be borne in mind that Fig. 8 represents no attempt to portray the conditions in any actual reservoir, but is illustrative only. Had the calculations

* The oil must spread on the water for this assumption to be completely valid.

been made on the basis of a greater assumed quantity of oil in the sand, the transitions from one saturation region to another would have been similar, but small quantities of oil would have been found in the gas sand at points higher relative to the gas-oil contact.

Additional theoretical and experimental work remains to be done on the three-fluid static distribution problem before it can be considered solved; however, certain qualitative deductions may be made with respect to the conditions encountered in oil reservoirs. Thus, it is to be expected that in any particular fairly uniform sand the transition zones from gas to oil and from oil to water will be fairly definite. Because of the shapes of the permeability-saturation[12,13] plots, the transition with height, of the composition of the fluids produced will be much more rapid than the corresponding transition of saturation with height. Probably the complete transition zone from 100 per cent water to 100 per cent oil in the produced fluids will often be only a few feet thick. However, even in a continuous reservoir these levels may vary several feet from one part of the sand to another as the permeability varies. It is probable that in nearly all cases the gas-oil contact will be more sharply defined and will exhibit less variation than the water-oil contact. Except in thin sands, where there may be partial overlapping of the contacts, it is to be expected that the existence of these transition zones will not materially interfere with proper well completion and not seriously impair reserve estimates based upon apparent thickness of the oil sand.

Motion of Fluid Mixtures in Porous Solids

Previous work on the flow of fluid mixtures in porous solids has failed adequately to account for all of the three influences that cause motion of the fluids: capillarity, gravity, and impressed external pressure differentials. We shall show briefly how these influences may be properly evaluated, with the aid of the concept of capillary pressure.

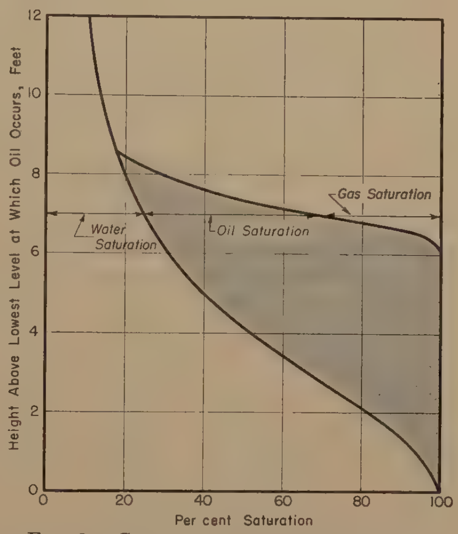

Fig. 8.—Calculated distribution of oil, gas, and water in a uniform unconsolidated sand.

Equations for Two-component Mixture Flow

Let us consider, for the sake of simplicity, the flow of a mixture of only two fluids, for example water and oil, in a porous solid in a gravitational field. By analogy to the well-known D'Arcy's law, we may write for the oil

$$q_{ou} = -\frac{K_o}{\mu_o}\left[\frac{\delta P_o}{\delta u} - g\rho_o \sin\alpha\right] \quad [9]$$

and for the water

$$q_{wu} = -\frac{K_w}{\mu_w}\left[\frac{\delta P_w}{\delta u} - g\rho_w \sin\alpha\right] \quad [10]$$

where q_{ou} and q_{wu} are the rates of oil and water flow in the direction u, per unit of cross-sectional area normal to u; $\left(\frac{\delta P_o}{\delta u}\right)$ and $\left(\frac{\delta P_w}{\delta u}\right)$ are the pressure gradients in the u direction in the oil and water, respectively; μ_o and μ_w are the oil and water viscosities;

α is the angle made by the direction u with the horizontal; K_o and K_w are the effective permeabilities[13] to oil and water, respectively, and the other symbols have their previous significance. Eqs. 9 and 10 are to be regarded as algebraic definitions of the effective permeabilities, and are statements of the fundamental law of viscous flow of fluid mixtures through porous media.

Since the water and oil are separated by curved interfaces the pressures in the two phases are not in general equal in the same plane normal to u. As a reasonable simplification, we shall *assume* that this pressure differential between the fluids is P_c, the capillary pressure, which would be calculated knowing the interfacial tension and curvature of the interface. The latter may, as shown previously, be determined approximately from the water saturation existing. Since, as defined, $P_c = P_o - P_w$, obviously

$$\left(\frac{\delta P_c}{\delta u}\right) = \left(\frac{\delta P_o}{\delta u}\right) - \left(\frac{\delta P_w}{\delta u}\right) \qquad [11]$$

Hence the pressure gradients in the two fluids are related by a quantity which, according to the above assumption, is a function of saturation gradient and saturation only. Further, the quantities K_o and K_w, effective permeabilities, have been shown to depend in steady mixture flow principally on the saturations existing.[12,13,19,20] A secondary effect of pressure gradient and interfacial tension on the effective permeabilities has been previously reported.[12] However, it is advisable tentatively to disregard this effect, since it now appears that it may possibly be merely a manifestation of the "boundary effect," and therefore not typical of the behavior of the interior of a large mass of sand. It is reasonable and convenient to *assume* that the effective permeabilities are functions of saturation only, for unsteady flow as well as steady. These two assumptions permit numerical evaluation of the rate of flow of both fluids at any point at which the saturation, saturation gradient and pressure gradient in one fluid are known. However, because of the necessity for evaluating the pressure gradient in one or the other fluid at every point in the system, these equations are not actually very useful. But this difficulty disappears for the special case of mixture flow in which (1) the total fluid rate per unit cross-sectional area

$$q_t = q_o + q_w \qquad [12]$$

is constant over each cross section normal to the direction of net flow, or varies in an explicitly known fashion, and (2) no motion of fluids occurs normal to the net flow direction. In this simplified case we may combine eqs. 9, 10 and 11 to give an expression for f_w, the fraction of water in the flowing stream passing any point in the sand:

$$f_w = \frac{1 + \dfrac{K_o}{q_t\mu_o}\left[\left(\dfrac{\delta P_c}{\delta u}\right) - g\Delta\rho \sin\alpha\right]}{1 + \dfrac{K_o}{K_w}\dfrac{\mu_w}{\mu_o}} \qquad [13]$$

This equation provides a relation between f_w, stream composition, and, by assumption, implicitly, water saturation and saturation gradient. It therefore suffices, together with appropriate boundary conditions, for the solution of any flow problem falling within the restrictions stated above. Such solutions are obtainable by numerical means.

Eq. 13 conveys a considerable amount of information regarding certain problems in oil production, but we shall forego detailed discussion of it until it can be shown to be quantitatively applicable. Good qualitative correspondence between theory and experiment have, however, already been observed in many cases.

The Boundary Effect

Discussion of capillarity in sands would be incomplete without particular mention of the special behavior of the fluids as they

flow past a discontinuity in the capillary properties of the porous medium. Such a discontinuity, for example, is the outflow face of a sand column.

In the interior of a uniformly saturated, uniform sand mass, no fluid flow due to capillarity occurs, since the pressures due to capillarity act equally in all directions, and hence exactly cancel each other.

At the outflow face of the sand column, however, there is a discontinuity in the capillary properties of the sand, since the water passes abruptly from a region of relatively high capillary pressure (the sand) into a void in which (since the restraint imposed by the sand grains is absent) the oil-water interface has no sensible curvature, and the capillary pressure therefore vanishes. Capillarity in the sand tends to draw the water into the sand from the void, a tendency that must be overbalanced by the impressed pressure gradient if water is to pass from the sand. Since part of the impressed pressure gradient goes to overcome the capillary pressure and hence is ineffective for overcoming frictional energy losses in the water, the water moves less rapidly than normally in the boundary. The water thus accumulates in the boundary grain layers, and the increased water saturation causes a decrease in the permeability to oil. The boundary thus makes egress of both oil and water more than normally difficult. This whole behavior will be called the "boundary effect."

Where water and oil are flowing steadily through the boundary, it is possible to show, and has been observed experimentally, that there is a saturation gradient, from a relatively high water saturation in the boundary to the lower one to be predicted for steady flow in the absence of capillary forces, or at a very large distance from the boundary. Similar behavior is observed in unsteady flow. The boundary effect thus involves distortion of the "normal" saturation profile in the sand. The distance to which appreciable distortion takes place can be shown (eq. 13) to vary directly with the interfacial tension of the fluids and the permeability of the sand, and inversely with oil viscosity and total liquid rate. Calculations show that, at ordinary reservoir flow rates, the boundary effect is confined to a zone a few feet in diameter near the well, therefore probably is not an important factor in behavior of arge-scale reservoirs. However, it is extremely important to recognize its existence and nature in interpreting the results of small-scale laboratory experiments. Indeed, it seems likely that many such experiments reported in the literature have been improperly interpreted because of failure adequately to account for the boundary effect.

Summary

The static equilibrium vertical distribution of fluids of different densities in porous solids has been discussed from a largely thermodynamic standpoint. The abandonment of the "capillary tube" concept of sand structure is urged, and the substitution of the concept of a characteristic distribution of interfacial two-fluid curvatures with water saturation is suggested. Experimental determination of this curvature-saturation relation for unconsolidated sands is described, and the results obtained are correlated so as to apply to all clean unconsolidated sands. The extent of the two-fluid interfacial surface area is shown to be determinable from thermodynamic consideration of the curvature-saturation relation.

The concepts developed are applied briefly to problems in the flow of mixtures of immiscible fluids in porous media, with emphasis on the proper accounting for the effects of capillarity on mixture flow. The existence of a *boundary effect*, characteristic of any discontinuity in the capillary properties of the solid medium, is pointed out. The importance of adequately accounting for its influence in the interpretation of data from small-scale flow experiments is stressed.

Acknowledgment

The author gladly acknowledges his indebtedness to Mr. W. R. Lobdell and Dr. G. G. Wrightsman, for assistance in the experimental work described, and to Mr. S. E. Buckley and Dr. W. B. Lewis, for helpful suggestions regarding preparation of material for this paper.

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DISCUSSION

D. L. Katz,* Ann Arbor, Mich.—Dr. Leverett's paper is a timely one and of particular interest to me. The percentages of oil saturation remaining in depleted oil sands based on flow experiments are of the order of 30 to 60 per cent liquid saturation. This concept has led us to neglect the ability of oil and water to drain of their own accord down to a final saturation of 8 to 10 per cent in the upper portion of thick sand sections. This means that oil will drain from thick permeable sands and reduce the final saturation much lower than any fluid drive could reduce it. It follows that claims for efficient recovery of oil from thick sands by fluid drives probably are unsound if compared with the recovery by drainage of the oil to the final saturations indicated in the paper.

It should be noted that Dr. Leverett bases the water-oil-sand relations on the preferential wetting of the sand by the water but states that exceptions to this preferential wetting by water may occur. This possibility that water does not preferentially wet the sand should not be forgotten when working with naturally occurring systems.

* Assistant Professor of Chemical Engineering, University of Michigan.

S. C. Herold,* Los Angeles, Calif.—Dr. Leverett's paper contributes to our knowledge of events within a producing reservoir in a manner aptly stated by S. E. Buckley just a year ago in the following words:[21]

"Regardless of the geometrical complexity of the conditions met in actual practice and the resulting difficulty in drawing exact conclusions, the underlying physical principles may be discovered through laboratory investigation, and once delineated and understood may be relied upon for the interpretation of the behavior of individual wells and of complete reservoirs. In fact, a knowledge of these principles is absolutely essential to any intelligent study of the drainage of oil and gas, the spacing of wells, the value of gas injection, or the use of water-flooding in secondary recovery operations."

The patient investigations of Muskat, Botset, Wyckoff and Lewis likewise clarify our conceptions of reservoir behavior. Field reservoirs are too complex and too erratic in their behavior, and there are too many factors in simultaneous action for us to rely upon them. In the laboratory it is a simple matter to eliminate in turn all the disturbing factors except the selected one for each particular investigation. A subsequent compilation of the results of necessity will reveal the performance of the well or that of the reservoir. The method is comparatively new in the oil industry, although it has had a general application in other sciences since the fourth century B. C. The industry is fortunate in having the work of these investigators. No longer need we deal with the uncertainties of field data,

* Consulting Petroleum Geologist and Engineer.
[21] S. E. Buckley: *Trans.* A.I.M.E. (1940) **136**, 104.

particularly where these data originate in observations by untrained individuals.

Mr. Leverett's suggestion that we discard the analogy between a sand and a bundle of straight, cylindrical capillary tubes is timely. Any such analogy is misleading. Uren first pointed this out some years ago in the following words:[22] "An oil sand is not a 'bundle of capillary tubes' converging on a well."

Furthermore, the idea that the Jamin effect can stop flow was discarded by Versluys in the following terms:[23] "J. Plateau proved that Jamin had not taken all the necessary precautions with his experiments. With the precautions Plateau took, the effect was much less. The writer believes that the Jamin effect would not be observed in a cylindrical tube, if it were possible to work more accurately than Plateau did." As a matter of fact, Plateau did the best he could to see that the tubes were clean. With the laboratory refinements of today, undoubtedly it is possible to improve upon Plateau's methods. This should in itself prove that the application of any such effect is now unwarranted. Botset came to this conclusion by experimentation with an ingenious electrical apparatus which showed very clearly that:[24] " . . . even in the case of mixtures any pressure gradient however small will cause fluid to move through a porous medium."

Buckley apparently agrees with this, for he said:[21] "It follows that so long as a pressure gradient exists in a continuous body of sand, flow will continue."

The preponderance of opinion obviously is against the concept of the capillary tube and in favor of the more realistic one; namely, "the concept of a characteristic distribution of interfacial two-fluid curvatures with water saturation," as offered by Leverett. This is clearer and in exact agreement with laboratory results. We cannot explain all that we observe in the field, but laboratory experimentation, supported by the integrations of the simpler partial differential equations of the second order and second degree, in time will reveal with precision that which we desire to know.

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Phase Behavior in the Methane-propane-n-pentane System

By R. T. Carter,* B. H. Sage,† Member A.I.M.E., and W. N. Lacey†

(Los Angeles Meeting, October 1940)

The phase behavior of a number of binary systems consisting of paraffin hydrocarbons has been determined in recent years. In addition, the composition of the coexisting phases of mixtures of crude oil and natural gas has been investigated.[1] However, the latter study did not include information concerning the influence of the concentration of a component upon its distribution between two coexisting phases. Owing to the paucity of such information it was considered desirable to investigate in some detail the composition of the coexisting phases in the methane-propane-n-pentane system throughout the greater part of the two-phase region at a temperature of 100°F. Information of this nature also permits the establishment of the critical behavior of this ternary system.

Method

The compositions of the coexisting phases in this ternary system at 100°F. were determined by withdrawing samples from a pressure vessel containing a heterogeneous mixture of the three components that had been brought to equilibrium by mechanical agitation at the desired pressure and temperature. The samples were withdrawn under such conditions that the equilibrium was not disturbed and the composition of each of the phases was ascertained by means of the conventional low-temperature fractionation procedure.

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[1] References are at the end of the paper.

The apparatus employed in this investigation was nearly the same as that utilized in an earlier study of the methane-n-pentane system.[2] Several minor modifications in the arrangement of the apparatus were made in the interest of simplifying the procedure and avoiding the possibility of condensation in the tubing connecting the equilibrium apparatus with the analytical equipment. The pressures were measured by means of a pressure balance with a precision of 0.5 lb. per sq. in. It is believed that the equilibrium pressure was ascertained with an uncertainty of not more than 2 lb. per sq. in., even though small variations in pressure obtained during the withdrawal of the samples. The temperature of the equilibrium equipment was maintained by use of an automatically controlled oil bath. The bath temperature was determined by means of a copper-constantan thermocouple, the electromotive force being determined by means of a potentiometric circuit of such a nature as to reduce the uncertainty of the temperature to less than 0.1°F.

The fractionating column employed in the determination of the composition of the gas phase had a diameter of 0.12 in. and was approximately 4 ft. long, while the column employed in the analysis of the liquid phase was 0.18 in. in diameter and about 5 ft. long. Each column was equipped with the conventional constant-volume receivers, which were maintained at a constant temperature by means of an automatically controlled oil bath. In nearly every case the distillation in the neighborhood of the transition between

one component and another was repeated in order to check the completeness of the separation of the components. The precision attained with the analytical equipment

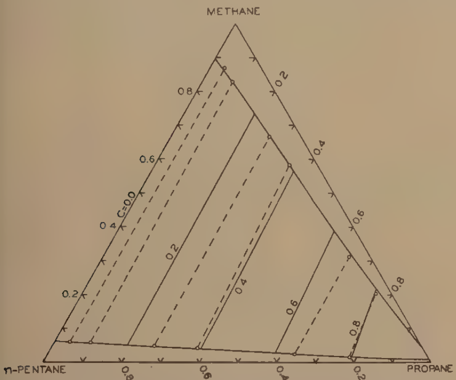

FIG. 1.—MOLAL COMPOSITION DIAGRAM AT 200 POUNDS PER SQUARE INCH AND 100°F.

was of the order of 0.001 mol fraction, while it is believed that the absolute uncertainty in the mol fraction of a component insofar as the analytical technique was concerned was less than 0.002 mol fraction.

However, this did not represent all of the uncertainty of measurement at low pressures. It was possible that very small amounts of liquid phase on the walls of the equilibrium chamber near the sample outlet were carried out with the sample of gas phase. At low pressures this entrainment may have increased the concentration of the heavier component to a marked extent. At higher pressures its influence would have been much less. It is probable, if all of the factors are considered, that the uncertainty in the mol fraction of a component in a phase was approximately 0.005. For this reason it is to be expected that the behavior of components present in relatively small amounts would not be established with sufficient accuracy to be of great engineering utility. However, for components present in reasonable quantity it is believed that the results are descriptive of actuality at least within 3 per cent.

MATERIALS

The methane used in this investigation was obtained from the Buttonwillow field in California. The material as received

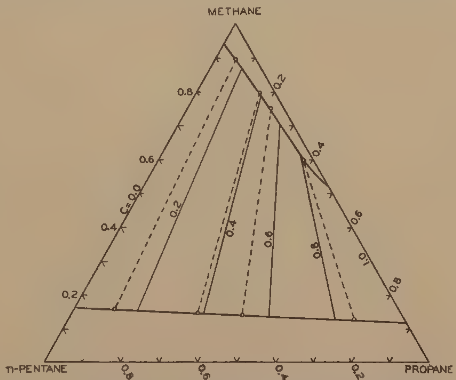

FIG. 2.—MOLAL COMPOSITION DIAGRAM AT 500 POUNDS PER SQUARE INCH AND 100°F.

was saturated with water and contained approximately 0.003 mol fraction of carbon dioxide and 0.0004 mol fraction of heavier hydrocarbons. Before use the material was passed successively through calcium chloride, potassium hydroxide, activated charcoal and Ascarite at pressures in excess of 500 lb. per sq. in. In addition, it was passed through a copper coil cooled with a mixture of solid carbon dioxide and acetone. It is believed that the material employed contained less than 0.001 mol fraction of material other than methane.

The propane used in this study was obtained from the Phillips Petroleum Co., whose analysis indicated that the maximum possible impurities would amount to less than 0.0005 mol fraction. The vapor pressure of samples of this hydrocarbon showed less than 0.2 lb. per sq. in. change during condensation from dew point to bubble point at a temperature of 160°F.

The *n*-pentane employed in this investigation was obtained from the Phillips Petroleum Co., whose analysis indicated that the material contained 0.995 mol fraction *n*-pentane and 0.005 mol fraction of isopentane. Before use the material

was deaerated by prolonged boiling at reduced pressures. The material was added to the equilibrium chamber in such a way as to avoid contact with the atmosphere.

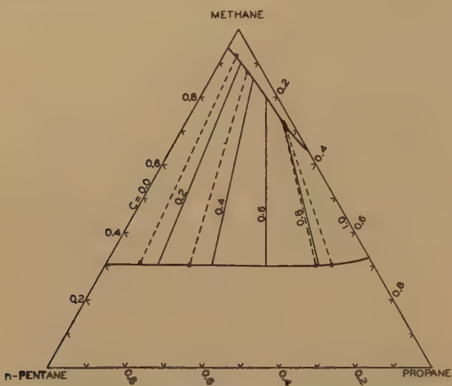

FIG. 3.—MOLAL COMPOSITION DIAGRAM AT 1000 POUNDS PER SQUARE INCH AND 100°F.

EXPERIMENTAL RESULTS

The experimental work relating to the behavior of this system was carried out during a two-year period and the results have been obtained using different procedures with regard to the details of the withdrawal of samples without apparently modifying the results significantly. All of the experimental results obtained at pressures above 500 lb. per sq. in.* have been recorded in Table 1. Similar measurements were made at 200 lb per sq. in., but owing to the importance of entrainment at low pressures and to the small quantity of material available for analysis, the composition of the gas was not established with the same accuracy as was attained at the higher pressures. Furthermore, the concentration of methane in the liquid phase was so small as to render its measurement difficult. For these reasons the results obtained at pressures below 500 lb. per sq. in. have not been reported in tabular form.

The compositions of the coexisting phases at 200, 500, 1000, 1500 and 2000 lb. per sq. in. are depicted in Figs. 1 to 5, inclusive. In each case dotted "combining lines"[2,3] connecting the coexisting phases have been included for the experimentally determined states. The solid combining lines

TABLE 1.—*Experimentally Determined Compositions of Coexisting Phases at 100°F.*

Pressure, Lb. per Sq. In. Abs.	Gas Phase			Liquid Phase		
	Methane	Propane	n-pentane	Methane	Propane	n-pentane
500	0.755[a]	0.218	0.027	0.139	0.446	0.415
	0.607	0.374	0.019	0.136	0.743	0.121
	0.796	0.164	0.040	0.147	0.324	0.529
	0.895	0.054	0.051	0.156	0.105	0.739
1000	0.716	0.262	0.023	0.306	0.589	0.105
	0.723	0.257	0.020	0.311	0.548	0.141
	0.871	0.088	0.041	0.302	0.220	0.478
	0.922	0.036	0.042	0.311	0.087	0.602
1500	0.812	0.145	0.043	0.469	0.289	0.242
	0.811	0.145	0.044	0.468	0.299	0.233
	0.808	0.148	0.044	0.470	0.301	0.229
	0.754	0.203	0.042	0.493	0.364	0.143
	0.862	0.085	0.053	0.454	0.187	0.359
	0.918	0.030	0.052	0.446	0.068	0.486
2000	0.818[b]	0.104	0.078	0.820	0.103	0.077
	0.669[b]	0.151	0.180	0.668	0.151	0.181
	0.856	0.057	0.087	0.609	0.096	0.295
	0.798	0.097	0.105	0.631	0.149	0.220
	0.875	0.042	0.083	0.600	0.066	0.334

[a] Compositions are expressed as mol fraction.
[b] Single-phase region.

shown are for even values of a parameter C which is defined by the following equation:

$$C = \frac{\underline{X}_3}{\underline{X}_3 + \underline{X}_5} \qquad [1]$$

The quantities $\underline{X}_3$ and $\underline{X}_5$ represent the mol fraction of propane and n-pentane, respectively, in the liquid phase. Information concerning the phase behavior of the three binary systems has been taken from earlier measurements relating to the methane-n-pentane,[4] methane-propane[5] and propane-n-pentane[6] systems. Figs. 1 to 5 show that the results are reasonably consistent with the earlier measurements for the binary systems containing methane.

The three sets of measurements at pressures of 1500 lb. per sq. in. for states with nearly the same composition indicate

* All pressures reported are absolute.

the agreement that was obtained between sets of duplicate measurements. In general, the agreement found is somewhat better than would be expected from the estimated uncertainty. The compositions as deter-

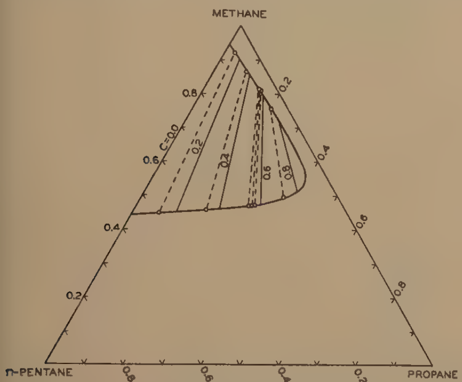

FIG. 4.—MOLAL COMPOSITION DIAGRAM AT 1500 POUNDS PER SQUARE INCH AND 100°F.

mined by the two fractionating columns from separate samples taken in the single-phase region are recorded in Table 1 and indicate the relative performance of the two pieces of equipment. These results indicate somewhat smaller uncertainty than was obtained in some of the heterogeneous equilibrium measurements in which entrainment was possible.

In order to aid in the visualization of the combined influence of pressure and composition upon the phase behavior of the system, an equilateral projection of a pressure-composition figure for the methane-propane-*n*-pentane system at 100°F. as viewed obliquely from above is presented in Fig. 6. The vapor pressures of propane and *n*-pentane depicted in this diagram were taken from published values.[7,8] The behavior of the methane-*n*-pentane system is described by the closed loop *ABCDE*, which is in the plane *ASQR* of this figure. Similarly, the loop *LMNO* depicts the behavior of the methane-propane system in the plane *LPQR*. The two-phase region of the propane-*n*-pentane system occupies only the very narrow area between *A* and *L* in plane *ASPL*.

The intersection of several isobaric planes with the figure has been indicated. For example, the behavior at 500 lb. per sq. in. is indicated by the figure *BEKOMG*. The similarity of this section with the

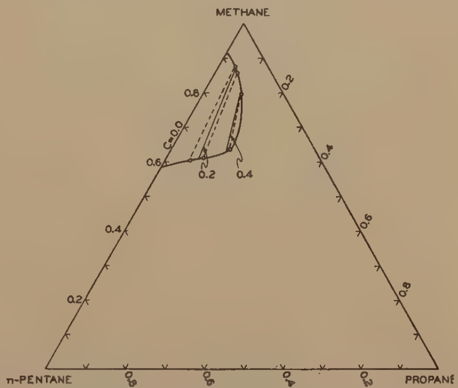

FIG. 5.—MOLAL COMPOSITION DIAGRAM AT 2000 POUNDS PER SQUARE INCH AND 100°F.

diagram of Fig. 2 is evident. The line *BGM* depicts the possible variations in the composition of bubble-point liquid, while the line *EKO* shows the variation in the composition of dew-point gas under the same conditions. As shown in Fig. 6, this pressure is below the critical pressure of both the methane-*n*-pentane and the methane-propane systems at 100°F. In each of the isobaric sections the "combining lines" corresponding to even values of the parameter *C*, which is defined by equation 1, have been indicated.

The behavior of the ternary system at a pressure of 1500 lb. per sq. in. is depicted by the plane figure *CDIH*. In this instance the pressure is above the critical pressure of the methane-propane system at this temperature and the existence of two phases at the intersection of this isobaric plane with the plane *LPQR* is impossible. The dotted locus *TN* has been included to show the variation in the critical pressure with the composition of the system. The data indicate that the maximum two-phase pressure at this temperature occurs at the critical state *T* of the methane-*n*-pentane system. There is a gradual decrease in the

critical pressure from this state at T to the critical state of the methane-propane system at N.

The behavior of a series of ternary mixtures subject to a common restraint with respect to variations in composition is depicted by the loop $FGHIJK$. This loop is characterized by the constancy of the parameter C at a value of 0.2 and is a figure of generation, since it intersects each isobaric plane in a straight combining line. The composition of a heterogeneous ternary mixture whose liquid phase yielded the given value of C would lie along this combining line corresponding to the pressure in question. Additional figures corresponding to any other value of this parameter could be depicted.

The pressure-composition diagram of Fig. 7 illustrates still further the nature of ternary systems subject to the above-described restricted variations in composition. The behavior of the methane-n-pentane and the methane-propane system is indicated as well as the pressure-composition relations of two ternary systems of such restricted composition variation that the ratio of propane to propane plus n-pentane in the liquid phase is maintained at a constant value. In this diagram the mol fraction of methane in each system has been depicted along the abscissa while the corresponding bubble-point and dew-point pressures are presented as the ordinates. In the methane-propane and methane-n-pentane systems the abscissa corresponding to zero mol fraction methane represents pure propane and pure n-pentane, respectively. In the two restricted ternary systems this point on the abscissa corresponds to a mixture of propane and n-pentane containing the designated relative amount of propane. For these cases there would be a separation of the dew-point and bubble-point lines for the ternary mixtures at zero mol fraction of methane.

TABLE 2.—*Equilibrium Constants for Components of Methane-propane-n-pentane System at 100°F.*

Pressure, Lb. per Sq. In. Abs.	C^a	Equilibrium Constants			Composition Gas Phase			Composition Liquid Phase		
		Methane	Propane	n-pentane	Methane	Propane	n-pentane	Methane	Propane	n-pentane
500	0	5.88	0.503	0.072	0.940[b]	0.000	0.060	0.160	0	0.840
	0.2	5.71	0.503	0.072	0.866	0.085	0.049	0.152	0.170	0.678
	0.4	5.51	0.504	0.075	0.788	0.173	0.039	0.143	0.343	0.514
	0.6	5.24	0.504	0.087	0.708	0.262	0.030	0.135	0.519	0.346
	0.8	4.87	0.522	0.125	0.613	0.365	0.022	0.126	0.699	0.175
	1.0	4.36	0.549		0.516	0.484	0	0.118	0.882	0
1000	0	3.08	0.403	0.077	0.947	0	0.053	0.308	0	0.692
	0.2	2.94	0.403	0.078	0.901	0.056	0.043	0.306	0.139	0.555
	0.4	2.80	0.404	0.084	0.853	0.112	0.035	0.304	0.278	0.418
	0.6	2.65	0.416	0.097	0.799	0.174	0.027	0.302	0.419	0.279
	0.8	2.39	0.458	0.155	0.723	0.255	0.022	0.304	0.557	0.139
	1.0	1.99	0.53		0.64	0.36	0	0.321	0.679	0
1500	0	2.14	0.437	0.105	0.941	0	0.059	0.439	0	0.561
	0.2	2.01	0.441	0.115	0.900	0.049	0.051	0.448	0.110	0.442
	0.4	1.86	0.458	0.147	0.853	0.099	0.048	0.459	0.216	0.325
	0.6	1.70	0.501	0.214	0.794	0.160	0.046	0.467	0.320	0.213
	0.8	1.40	0.626	0.432	0.711	0.246	0.043	0.508	0.394	0.098
2000	0	1.58	0.572	0.204	0.914	0	0.086	0.579	0	0.421
	0.2	1.44	0.581	0.263	0.871	0.046	0.083	0.606	0.079	0.315
	0.4	1.28	0.646	0.460	0.801	0.096	0.103	0.628	0.149	0.223

[a] See equation 1.
[b] Compositions are expressed as mol fraction.

EQUILIBRIUM CONSTANTS FOR THE COMPONENTS

The ratio of the mol fraction of a given component in the gas phase to its mol fraction in a coexisting liquid phase has been

called an "equilibrium constant." Actually this ratio is a function of the state of the heterogeneous system although under certain conditions where the components ap-

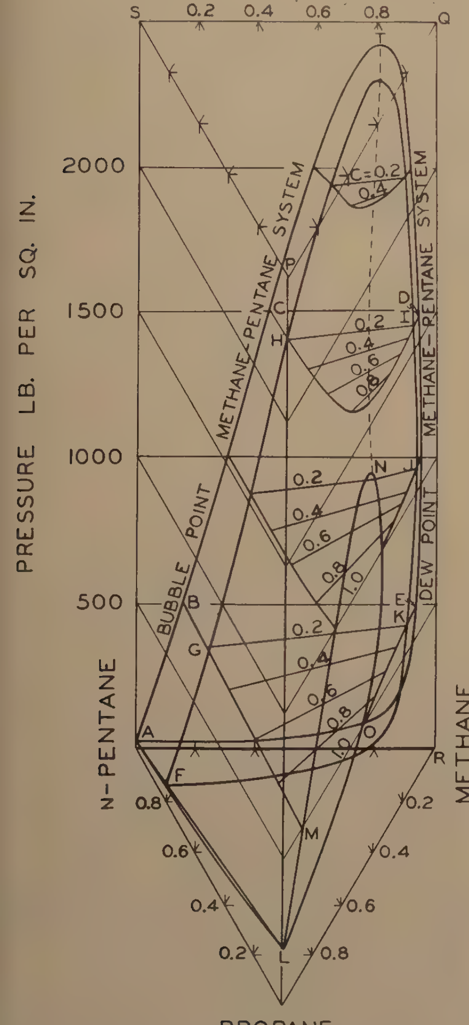

FIG. 6.—MOLAL COMPOSITION-PRESSURE DIAGRAM FOR TERNARY SYSTEM AT 100°F.

proach the laws of ideal solution rather closely it is primarily a function of pressure and temperature and is nearly independent of the nature and amount of the other components present.

From the experimental data recorded in Table 1 the corresponding equilibrium constants for each of the components were calculated. The results were interpolated to even values of the relative quantity of propane and n-pentane in the liquid phase

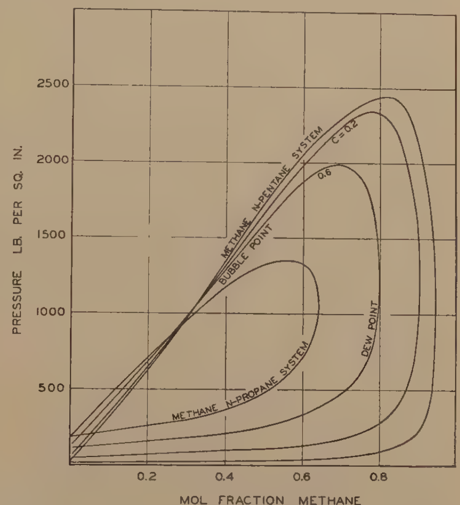

FIG. 7.—EFFECT OF METHANE UPON BUBBLE-POINT AND DEW-POINT PRESSURES AT 100°F.

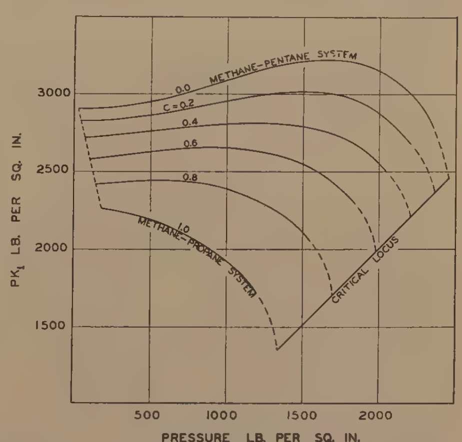

FIG. 8.—EQUILIBRIUM CONSTANTS FOR METHANE IN THE METHANE-PROPANE-n-PENTANE SYSTEM AT 100°F.

as measured by the parameter C of equation 1. The variation in the equilibrium constants for methane with pressure for different ratios of propane to propane plus pentane in the liquid phase is presented in Fig. 8. The product of the equilibrium constant and the pressure has been employed

in this diagram in order to depict the influence of environment upon the equilibrium constants for methane with greater precision than would be possible by plotting the equilibrium constant itself. The values describing the behavior of methane in the pertinent binary systems were obtained from information already available in the literature.[4,5] However, the equilibrium constants of methane in the methane-n-pentane system have been modified slightly from the earlier values[4] in order to bring these results into agreement with more recent measurements, which are as yet unpublished. There were insufficient data to ascertain with accuracy the influence of environment upon the equilibrium constant in the neighborhood of the critical state. For this reason the curves in Fig. 8 have been dotted at the higher pressures. It should be realized that the extremities of these curves at low pressures correspond to the behavior of methane at infinitesimal concentration in mixtures of propane and n-pentane whose liquid-phase composition corresponds to the value of C indicated.

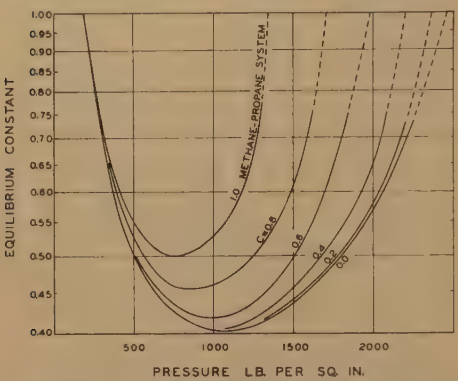

FIG. 9.—EQUILIBRIUM CONSTANTS FOR PROPANE IN THE METHANE-PROPANE-n-PENTANE SYSTEM AT 100°F.

The influence of the state of the system upon the equilibrium constants of propane is shown in Fig. 9. A logarithmic ordinate scale has been employed to present these data to better advantage than would the use of a linear scale. The experimental information indicates an appreciable influence of the nature and amount of the other components upon the behavior of propane at pressures as low as 500 lb. per sq. in. At the higher pressures these influences become of importance comparable to that of pressure. However, the influence of the composition of the liquid phase apparently is less significant in mixtures containing small amounts of propane than in those rich in this component. This is indicated by the proximity of the lines corresponding to small values of C while there is a rather wide separation between the curves corresponding to values of C near unity. Again the experimental information was insufficient to establish with accuracy the behavior in the vicinity of the critical states, which accounts for the dotted portion of the curves at the higher pressures.

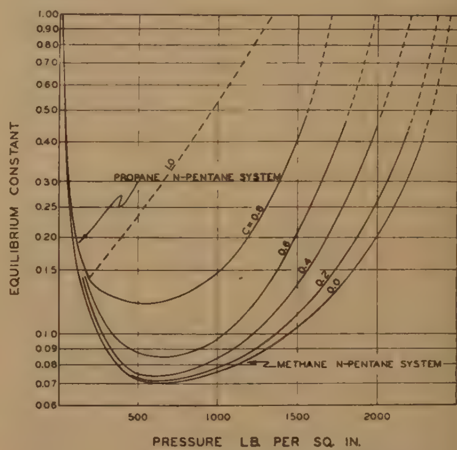

FIG. 10.—EQUILIBRIUM CONSTANTS FOR n-PENTANE IN THE METHANE-PROPANE-n-PENTANE SYSTEM AT 100°F.

Similar information for n-pentane is shown in Fig. 10, in which the equilibrium constant is again presented upon a logarithmic scale. The data were not accurate enough to permit the estimation of the behavior of n-pentane in the part of the ternary system containing very little of this component. For that reason the dotted curve corresponding to the behavior of n-pentane in the methane-propane system

can be considered as being only qualitative. The behavior of *n*-pentane in the propane-*n*-pentane system was estimated from earlier measurements[6] upon this binary system.

The information presented in Fig. 10 indicates that at pressures as low as 300 lb. per sq. in. there is still an appreciable influence of the nature and amount of the other components upon the phase behavior of *n*-pentane. Moreover, at higher pressures this influence becomes of the same order of importance as the pressure. As for propane, the most marked variations in the equilibrium constant at a particular pressure and temperature are found at the higher concentrations of propane while in the vicinity of the methane-*n*-pentane system the effect of small variations in the relative amount of propane is not great.

Summary

This study of the phase behavior of the methane-propane-*n*-pentane system indicated that at 100°F. the critical pressures of the ternary mixtures are less than the critical pressure of the binary mixture whose components exhibit the maximum divergence in critical temperature. However, the experimental work was not complete enough to establish the critical behavior with great accuracy and it is possible that a small maximum might exist in the ternary region in the immediate vicinity of the methane-*n*-pentane axis. The experimental measurements indicate a marked influence of the nature and amount of other components upon the phase behavior of these lighter paraffin hydrocarbons. These effects are appreciable in propane and *n*-pentane at a pressure of 500 lb. per sq. in. and pervade the entire two-phase region for methane. Such a great dependence of the equilibrium constants upon the nature and amounts of the other components present detracts appreciably from their usefulness. It becomes necessary to consider this "constant" to be a function of the state of the heterogeneous system rather than a quantity that is a function only of pressure and temperature. The variations are so pronounced as to render the prediction of the phase behavior of systems of this nature from generalizations based alone upon variations in pressure and temperature of little avail at pressures in excess of 1000 lb. per sq. inch.

It is possible that the chemical potential of a component in a phase may be employed along with the pressure and temperature as an index of thermodynamic equilibrium. Under these circumstances the prediction of the phase behavior is simplified somewhat, since the chemical potential is a function only of the state of a phase rather than of the state of the heterogeneous system as a whole. Furthermore, such means of prediction would interrelate the phase behavior with the volumetric and thermal properties of the system. However, the prediction of the chemical potential of a component in a phase requires detailed information concerning the partial volumetric behavior of that component from infinite attenuation to the pressure in question throughout the range of compositions of interest and little experimental information of this nature is at present available.

Acknowledgment

The work reported here was made possible by financial assistance from the Standard Oil Company of California through a fellowship grant. Some of the determinations included were made by George Wald, Jr.

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DISCUSSION

C. L. Horine,* Long Beach, Calif.—This is one of the few cases in which a three-component hydrocarbon system (that is, a mixture of three pure substances found in petroleum) has been studied to any great extent. Because research workers have been able to devise such a solid theoretical background with which to predict the general behavior of three-component systems, there has been little academic interest in the actual experimentation with them. However, from the standpoint of the petroleum industry, these results form another essential building block in the process of gathering fundamental information about these hydrocarbons that daily we work with—or for.

It is true, as some may point out, that the industry seldom has instances in which engineering calculations would be desired for mixtures of only methane, propane and normal pentane. However, the results given in this paper could be used to help check, modify, or expand the equilibrium constants already published by these authors as Tentative Equilibrium Constants for Light Hydrocarbons. Recently we used the latter paper, along with other data, to calculate the bubble point and formation-volume factor for a section of the Coalinga Nose oil field. The practical application of such calculations can be seen when it is remembered that the bubble point is that point on the reduction of pressure at which the first bubble of gas appears from what previously was a complete liquid or oil phase; and the formation-volume factor is the factor with which the barrels of pore, or void, space in a petroleum reservoir can be converted to barrels of tank oil on the surface of the ground. Calculations of this type, when they are possible, involve a great deal less expense and less costly laboratory equipment than would direct measurements of these points and factors in the laboratory.

* The Texas Company.

In connection with the expansion of these equilibrium constants, it might be noticed that the data in this paper indicate that the effect of composition on equilibrium constants is greatest for components of higher molecular weight; that is, the heavier components.

It is, perhaps, unfortunate that experimental conditions make it difficult or impossible to obtain good data for such mixtures as these at pressures below 500 lb. per sq. in. Such data could serve as direct experimental checks on the accuracy of equilibrium constants that are being used at present by the industry—mainly in connection with the manufacturing of natural gasoline. Such data likewise would indicate the degree to which equilibrium constants at lower pressures are dependent on composition.

The authors have suggested the use of an additional concept, "chemical potential." This term is new to many of us, and, therefore, somewhat disagreeable. However, the cold facts are that the entire subject of the phase behavior of petroleum mixtures is exceedingly complex. Almost no headway can be made on problems in this field without the fundamental experimental work that is being done by such men as Dr. Sage and Dr. Lacey. If research workers in this field believe that a more logical and, in the end, more time-saving and economical approach to the whole subject can be made by the use of additional concepts, such as chemical potentials, and if they make these data available, technical men in the industry should not hesitate to use them.

Volumetric Behavior of Oil and Gas from the Rio Bravo Field

By B. H. Sage,* Member A.I.M.E., and H. H. Reamer*

(Los Angeles Meeting, October 1940)

Attempts have been made to predict the volumetric and phase behavior of naturally occurring hydrocarbon mixtures[1-5] but these methods have not been extended to the higher pressures and temperatures that are currently encountered in some producing formations. Furthermore, the methods of prediction at present available have not been tested in a sufficient number of cases to ensure their applicability to all naturally occurring hydrocarbon mixtures, even at the lower pressures and temperatures. For these reasons the behavior of a number of hydrocarbon mixtures from a field in which the subsurface pressures are above 4500 lb. per sq. in.† and the temperatures are in the neighborhood of 250°F. was investigated.

Method

The objective of this program was to determine the volumetric behavior of material as it existed in the reservoir as a function of pressure, temperature and composition. Strictly speaking, this cannot be accomplished in any simple fashion. However, the variations in composition that are encountered within a producing reservoir may be approximated roughly by means of mixtures made up of two arbitrarily chosen constituents. Experience indicates that the liquid and gas phases from a high-pressure gas trap afford a simple source of material for this purpose. Throughout this discussion the samples of the gas phase and liquid phase from the production trap will be called the "trap-gas sample" and the "trap-liquid sample," respectively.

The volumetric behavior of both of the trap samples was determined throughout the temperature interval between 100° and 250°F. at pressures up to 5000 lb. per sq. in. In addition, the behavior of eight different mixtures containing varying proportions of the two trap samples was studied throughout the same temperature and pressure intervals. The experimental results yielded information concerning the specific volume of the material as a function of pressure, temperature and the relative quantity of the trap samples.

The relative amount of each of the paraffin hydrocarbons of lower molecular weight than *n*-hexane was determined for each of the trap samples. In addition, the specific weight, viscosity and average molecular weight of the hexanes-and-heavier fraction of the trap-liquid sample were determined as well as similar information for each of five fractions separated from this material by distillation. From these data the weight fractions of each of the components from methane through pentane were determined for the trap samples and eight systematically chosen mixtures.

Materials

The gas and liquid samples were obtained from the production trap of a well in the Rio Bravo field in California during the fall of 1939. Information concerning the condi-

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* Gates and Crellin Laboratories of Chemistry, California Institute of Technology, Pasadena, California.

[1] References are at the end of the paper.

† All pressures reported are absolute.

tion of the well and the nature of the production at the time of sampling is recorded in Table 1. There was some indication of the presence of a plastic material, sometimes called "bitumen," in the well under the conditions of production then obtaining.

TABLE 1.—*Sampling Conditions*

Field	Rio Bravo
Approximate depth of well, ft.	11,500
Gas-oil ratio, cu. ft. per bbl	1040
Gravity of oil, deg. A.P.I.	39.9
Trap pressure, lb. per sq. in. abs.	465
Approximate subsurface pressure, lb. per sq. in. abs.	4750
Approximate subsurface temperature, deg. F.	250

Both the trap-liquid and trap-gas samples were obtained in duplicate and subsamples were taken for analysis. Before material was withdrawn from the gas-sample container it was heated to 280°F. for several hours and subjected to some mechanical agitation to avoid inhomogeneities in the gas phase. The pressure within the liquid-sample container was raised to about 1000 lb. per sq. in. by the addition of mercury and the material was agitated for an extended period in order to assure the existence of a homogeneous liquid phase before material was withdrawn from it. The liquid phase was transferred from the sample container by means of quiescent water displacement.

TABLE 2.—*Composition of Trap Samples*

Gas	Gas: Mol Fraction	Gas: Weight Fraction	Liquid: Mol Fraction	Liquid: Weight Fraction
Methane	0.8602	0.7152	0.1058	0.01499
Ethane	0.0770	0.1200	0.05452	0.01448
Propane	0.0426	0.0973	0.08716	0.03395
Isobutane	0.0057	0.0172	0.02242	0.01151
n-butane	0.0087	0.0262	0.09465	0.04860
Isopentane	0.0011	0.0041	0.02092	0.01334
n-pentane	0.0014	0.0052	0.02587	0.01649
Hexanes	0.0033	0.0147		
Fractions:				
188°F.[a]				0.08949
238°F.				0.09380
332°F.				0.09821
440°F.				0.1024
543°F.				0.1050
Residue				0.3576
Hexanes and heavier			0.5887	0.8466

[a] Average boiling point.

The compositions of the trap-gas and trap-liquid samples are recorded in Table 2, where the weight and mol fractions of the paraffin hydrocarbons of lower molecular weight than hexane are tabulated. The weight fractions of the "cuts" obtained from the fractionation of the heavier material in the trap-liquid sample are also recorded in this table. All of the material in the trap-gas sample of greater molecular weight than *n*-pentane was reported as hexane. Certain properties of the fractions from the hexanes-and-heavier portion of the trap-liquid sample are recorded in Table 3.

LABORATORY PROCEDURE

The apparatus and methods employed in this investigation have been described recently.[6,7,8] The use of the two different pieces of equipment assisted materially in ascertaining the behavior of this system since each was better adapted to investigations in certain regions. The trap-liquid sample was dried before it was introduced into the apparatus, by contact with granular calcium chloride that had been brought to equilibrium with the dry sample. The quantity of the liquid sample added was determined from a knowledge of the change in total volume resulting from the withdrawal of a known weight of the material from the apparatus. This procedure permitted the direct evaluation of the weight of trap-liquid sample employed in a particular set of measurements. In the study of the trap-gas sample and of mixtures of the trap samples, the quantities of gas employed were determined gravimetrically by the weighing-bomb technique described recently.[6]

These procedures permitted the establishment of the weight of each of the trap samples utilized. with an uncertainty of not more than 0.2 per cent. However, some difficulty was experienced in obtaining re-

producible samples of trap liquid from the original container. Variations in bubble-point pressures of as much as 2 per cent were encountered between different samples of material taken from the container. However, there was no tendency for these pressures to decrease in a regular manner with time, as might have been expected in the event of a leak in the sample container. This, as well as other evidence, indicates the need of great care in the withdrawal of liquid samples from containers since concentration gradients persist within the body of the liquid phase even after extended periods of agitation.

It is believed that the uncertainty in the measurement of pressure was not more than 0.1 per cent while the temperature was determined within 0.1°F. relative to the international platinum scale. The total volumes of the samples were determined with an uncertainty of about 0.2 per cent throughout the range of conditions covered. However, difficulty in obtaining representative samples from the original containers introduced uncertainties as large as 0.4 per cent. At the lowest gas-oil ratios and also at the higher pressures and gas-oil ratios where appreciable quantities of bitumen were separated, the over-all uncertainty was probably as large as 1.5 per cent.

TABLE 3.—*Properties of Hexanes-and-heavier Fraction of Trap-liquid Sample*

Cut No.	Gravity, Deg. A.P.I. 60°F.	Kinematic Viscosity, Centistokes				Viscosity Gravity Factor	Average Boiling Point, Deg. F.	Average Molecular Weight	Weight Fraction
		77°F.	100°F.	130°F.	210°F.				
Fraction	35.2	5.11	3.58			0.835		162.8[a]	0.8466
1[b]	63.1	0.589	0.524			0.777	188[c]	100[c]	0.08949
2	54.2	0.775	0.680			0.805	238	107	0.09380
3	45.7	1.177	0.999			0.829	332	137	0.09821
4	38.6	2.40	1.89			0.841	440	179	0.1024
5	34.4	5.24	3.81			0.843	543	230	0.1050
Residue	19.5			71.75	13.16	0.885		402	0.3577

[a] Determined from freezing-point lowering of benzene, extrapolated to infinite dilution.
[b] Separated from fraction by distillation at atmospheric pressure.
[c] Calculated from physical properties, *Oil and Gas Jnl.* (July 2, 1936).

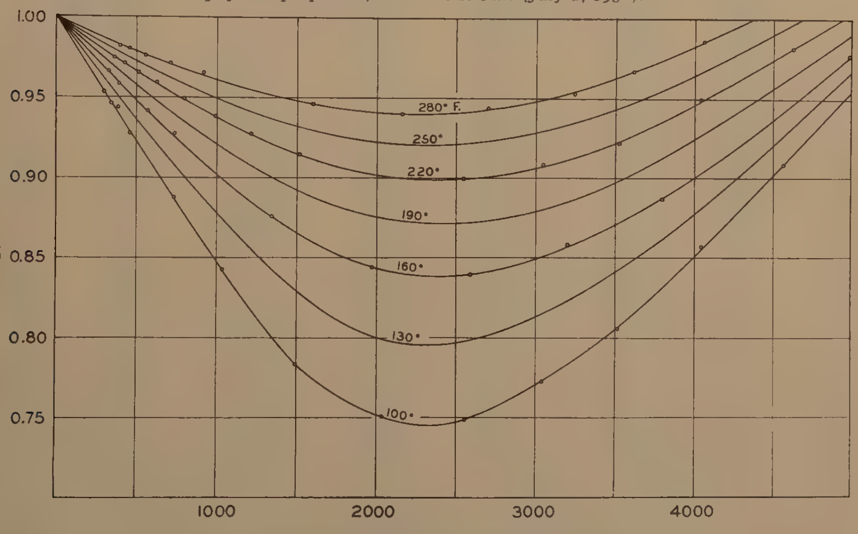

FIG. 1.—COMPRESSIBILITY FACTOR FOR TRAP-GAS SAMPLE.

Experimental Results

The behavior of the trap-gas sample was investigated experimentally at four temperatures between 100° and 280°F. at pressures from 300 to over 5000 lb. per sq. in. Since the weight of gas employed in these investigations and its total volume as a function of pressure were known, the average molecular weight could be predicted by extrapolation of the pressure-volume product to zero pressure, making use of the following expression:*

$$M_a = RT/(PV)_0 \qquad [1]$$

The value thus ascertained was found to deviate somewhat from that computed from the analysis. This discrepancy may be attributed in part to uncertainties in the volumetric study but probably results primarily from uncertainties in sampling and from assumptions concerning the nature of the hydrocarbons in the sample of greater molecular weight than *n*-pentane. In order to avoid introducing an inconsistency, the results have been reported in terms of the "compressibility factor" which corresponds to the ratio of the pressure-volume product for the actual gas to its pressure-volume product at zero pressure for the same temperature.

Table 4.—*Compressibility Factors for Trap-gas Sample*

Pressure, Lb. per Sq. In. Abs.	100°F.	130°F.	160°F.	190°F.	220°F.	250°F.	280°F.
0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
20	0.9973	0.9976	0.9978	0.9983	0.9986	0.9988	0.9990
40	0.9940	0.9955	0.9960	0.9965	0.9973	0.9977	0.9981
60	0.9908	0.9922	0.9939	0.9949	0.9955	0.9965	0.9972
100	0.9845	0.9870	0.9893	0.9914	0.9928	0.9943	0.9955
150	0.9765	0.9804	0.9840	0.9870	0.9893	0.9915	0.9935
200	0.9687	0.9741	0.9789	0.9829	0.9860	0.9888	0.9912
300	0.9530	0.9612	0.9685	0.9745	0.9791	0.9832	0.9870
400	0.9375	0.9485	0.9585	0.9664	0.9726	0.9780	0.9829
500	0.9220	0.9360	0.9485	0.9582	0.9663	0.9728	0.9789
600	0.9068	0.9238	0.9390	0.9504	0.9601	0.9678	0.9750
700	0.8915	0.9118	0.9295	0.9428	0.9543	0.9628	0.9712
800	0.8765	0.9000	0.9200	0.9353	0.9485	0.9580	0.9678
1000	0.8470	0.8778	0.9022	0.9212	0.9375	0.9493	0.9610
1250	0.8120	0.8516	0.8822	0.9057	0.9251	0.9400	0.9538
1500	0.7835	0.8289	0.8650	0.8924	0.9147	0.9320	0.9477
1750	0.7633	0.8112	0.8498	0.8820	0.9065	0.9260	0.9430
2000	0.7515	0.8000	0.8430	0.8750	0.9010	0.9220	0.9403
2250	0.7457	0.7955	0.8387	0.8713	0.8985	0.9203	0.9397
2500	0.7469	0.7967	0.8385	0.8710	0.8988	0.9210	0.9405
2750	0.7567	0.8027	0.8422	0.8731	0.9013	0.9238	0.9430
3000	0.7700	0.8120	0.8492	0.8783	0.9059	0.9281	0.9475
3250	0.7861	0.8255	0.8589	0.8864	0.9123	0.9345	0.9535
3500	0.8049	0.8405	0.8705	0.8971	0.9212	0.9427	0.9620
3750	0.8263	0.8578	0.8848	0.9100	0.9327	0.9530	0.9718
4000	0.8503	0.8765	0.9005	0.9244	0.9461	0.9645	0.9827
4250	0.8754	0.8975	0.9184	0.9400	0.9597	0.9772	0.9942
4500	0.9013	0.9200	0.9375	0.9564	0.9739	0.9905	1.0055
4750	0.9275	0.9430	0.9573	0.9733	0.9895	1.0040	1.0183
5000	0.9545	0.9664	0.9774	0.9903	1.0055	1.0175	1.0310

Results of the experimental work upon the trap-gas sample are depicted in Fig. 1. The points shown are the directly measured experimental values and their average deviation from the smooth curve was approximately 0.1 per cent. Values of the compressibility factor interpolated to even values of pressures are recorded in Table 4. It is believed that these results represent the behavior of the gas investigated with an uncertainty of not more than 0.3 per cent. However, uncertainty as to the average molecular weight may introduce discrepancies of as much as 2 per cent in

* A table of nomenclature is given at the end of the paper.

estimating the volumetric behavior from generalizations making direct use of the composition of the gas.

The trap-liquid sample was investigated were chosen at even values of weight fraction of the trap-gas sample to cover the composition range of the investigation with a density comparable to that of the original

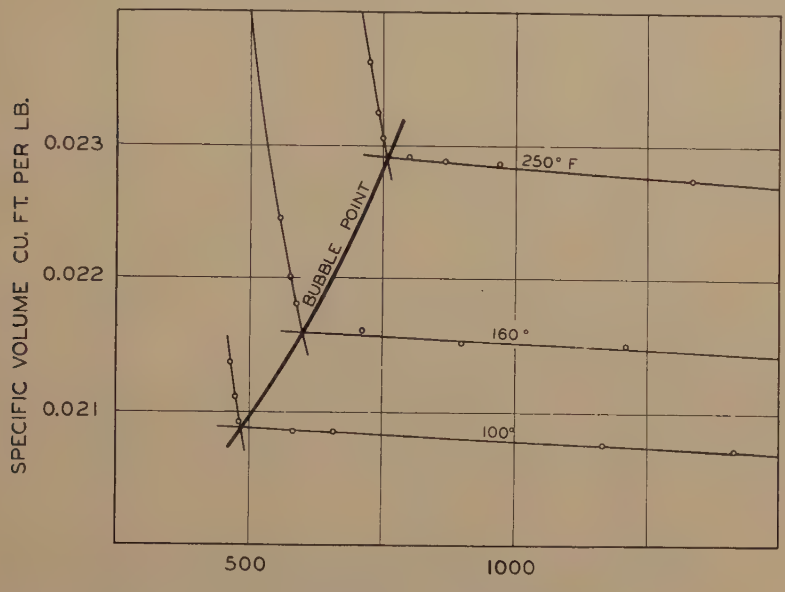

FIG. 2.—SPECIFIC VOLUME OF TRAP-LIQUID SAMPLE NEAR BUBBLE POINT.

at 100°, 160° and 250°F. and a typical set of results obtained from one of three samples investigated for states in the vicinity of bubble point is shown in Fig. 2. The different samples agreed with one another within 0.3 per cent in specific volume but the value of bubble-point pressure showed a maximum variation of approximately 2 per cent from sample to sample. The specific volumes and bubble-point pressures for the trap-liquid sample are recorded in Table 5. The experimental measurements upon three different samples showed an average deviation of 0.2 per cent from the values recorded. This material showed an increase in bubble-point pressure with an increase in temperature but this effect became less pronounced at the higher temperatures.

The compositions of the mixtures of trap samples are recorded in Table 6. Mixtures experimental data. A typical set of experimental results for a mixture of the trap

TABLE 5.—*Specific Volumes for Trap-liquid Sample*

Pressure, Lb. per Sq. In. Abs.	At 100°F.	At 160°F.	At 190°F.	At 250°F.
Bubble point	(484)[a] 0.02088[b]	(600) 0.02158	(654) 0.02201	(758) 0.02291
200		0.05610		
300		0.03720	0.04273	0.05378
400		0.02863	0.03220	0.03935
450	0.02182	0.02609	0.02904	0.03495
500	0.02087	0.02420	0.02670	0.03169
600	0.02085	0.02164	0.02349	0.02720
700	0.02083	0.02157	0.02247	0.02423
800	0.02081	0.02155	0.02198	0.02290
1000	0.02078	0.02151	0.02192	0.02284
1250	0.02073	0.02146	0.02187	0.02276
1500	0.02069	0.02142	0.02182	0.02269
1750	0.02064	0.02137	0.02177	0.02262
2000	0.02059	0.02132	0.02172	0.02254
2250	0.02055	0.02128	0.02167	0.02247
2500	0.02050	0.02123	0.02161	0.02239
2750	0.02045	0.02118	0.02156	0.02232
3000	0.02040	0.02113	0.02151	0.02224
3250	0.02035	0.02108	0.02145	0.02216

[a] Bubble-point pressure, lb. per sq. inch.
[b] Specific volume, cu. ft. per pound.

samples is presented in Fig. 3. The agreement of the experimental points with the smoothed values was satisfactory, although some difficulty was experienced in connection with this mixture in the separation of an essentially plastic phase at the higher pressures and temperatures. The results shown in Fig. 3 and those obtained for seven other mixtures were interpolated to even values of the weight fraction of the trap-gas sample and of pressure. The results of this interpolation are recorded in Table 7. It is believed that this graphic process was carried out with such precision that no added uncertainties greater than 0.15 per cent were introduced. It is believed that

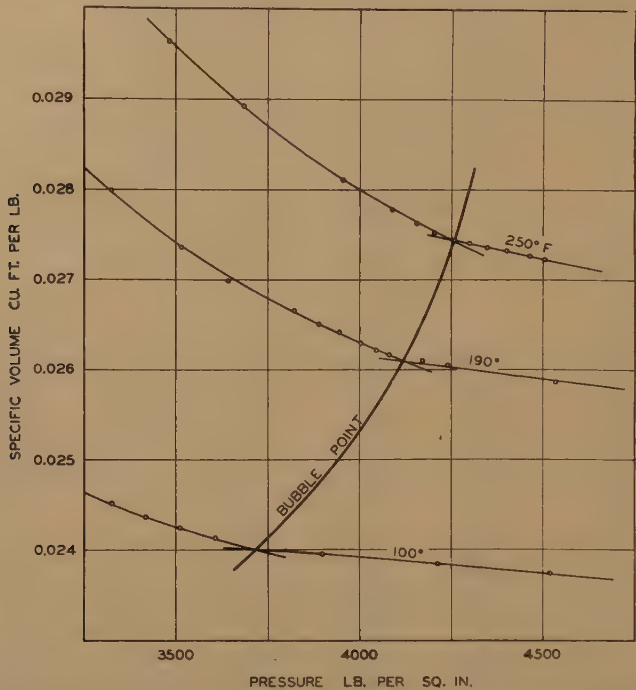

FIG. 3.—SPECIFIC VOLUME NEAR BUBBLE POINT OF MIXTURE CONTAINING 0.1608 WEIGHT FRACTION OF TRAP-GAS SAMPLE.

TABLE 6.—*Compositions of Mixtures of Trap Samples*

Component	Weight Fraction Trap-gas Sample							
	0.02	0.04	0.06	0.08	0.10	0.12	0.16	0.18
Methane	0.02899[a]	0.04300	0.05700	0.07101	0.08501	0.09902	0.1270	0.1410
Ethane	0.01659	0.01870	0.02081	0.02292	0.02503	0.02714	0.03136	0.03347
Propane	0.03522	0.03648	0.03776	0.03902	0.04029	0.04156	0.04409	0.04536
Isobutane	0.01162	0.01174	0.01185	0.01196	0.01215	0.01219	0.01242	0.01253
n-butane	0.04815	0.04770	0.04725	0.04681	0.04636	0.04592	0.04501	0.04457
Isopentane	0.01315	0.01297	0.01279	0.01260	0.01241	0.01223	0.01186	0.01168
n-pentane	0.01627	0.01604	0.01581	0.01558	0.01536	0.01514	0.01469	0.01446
Hexanes +	0.8300	0.8134	0.7967	0.7801	0.7635	0.7468	0.7136	0.6969
Gas[b]	0.1700	0.1866	0.2033	0.2199	0.2366	0.2532	0.2864	0.3031
Gas-oil ratio[c]	612.80	757.73	908.4	1065.6	1229.8	1401.0	1767.3	1964.0

[a] Compositions are expressed as weight fraction.
[b] Hydrocarbons from methane to *n*-pentane, inclusive.
[c] Based upon pentane-free oil and expressed as cubic feet per barrel measured at 60°F. and 14.73 lb. per sq. inch.

TABLE 7.—*Specific Volumes of Mixtures of Trap Samples*

Temperature, deg. F.	Pressure, Lb. per Sq. In. Abs.	Weight Fraction Trap-gas Sample								
		0.00	0.02	0.04	0.06	0.08	0.10	0.12	0.16	0.18
100	Bubble point	(480)[a] 0.02088[b]	(895) 0.02124	(1315) 0.02163	(1715) 0.02205	(2085) 0.02254	(2427) 0.02308	(2750) 0.02366	(3355) 0.02502	(3645) 0.0258
	600	0.02085	0.02710	0.03581	0.04453	0.05326	0.06189	0.07013		
	700	0.02083	0.02429	0.03150	0.03875	0.04607	0.05330	0.06048	0.0753	0.083
	800	0.02081	0.02250	0.02873	0.03492	0.04108	0.04715	0.05310	0.0656	0.072
	1000	0.02078	0.02121	0.02477	0.02940	0.03403	0.03865	0.04328	0.0529	0.058
	1250	0.02073	0.02115	0.02209	0.02558	0.02910	0.03248	0.03588	0.0428	0.04622
	1500	0.02069	0.02109	0.02156	0.02323	0.02597	0.02873	0.03152	0.03703	0.03975
	2000	0.02059	0.02101	0.02146	0.02196	0.02292	0.02475	0.02655	0.03012	0.03192
	2500	0.02050	0.02091	0.02135	0.02187	0.02243	0.02304	0.02428	0.02684	0.02812
	3000	0.02040	0.02082	0.02126	0.02175	0.02231	0.02289	0.02353	0.02515	0.0260
	3500	0.02031	0.02071	0.02116	0.02166	0.02221	0.02277	0.02338	0.02492	
	4000	0.02023	0.02062	0.02107	0.02156	0.02209	0.02264	0.02323	0.02473	
190	Bubble point	(600) 0.02201	(1095) 0.02248	(1580) 0.02297	(2045) 0.02347	(2500) 0.02398	(2901) 0.02451	(3300) 0.02508	(4055) 0.02631	(4405) 0.02701
	600		0.0335	0.0451	0.0567	0.0684	0.0801	0.0917		
	700	0.02247	0.0299	0.0396	0.0490	0.0589	0.0687	0.0784	0.0978	
	800	0.02198	0.0270	0.0350	0.0431	0.0514	0.0594	0.0675	0.0837	
	1000	0.02192	0.0236	0.0300	0.03633	0.04271	0.0491	0.0556	0.0684	0.0748
	1250	0.02187	0.02243	0.02609	0.03070	0.03545	0.04042	0.0453	0.0550	0.0599
	1500	0.02182	0.02232	0.02355	0.02722	0.03093	0.03465	0.03836	0.0462	0.0498
	2000	0 02170	0.02217	0.02278	0.02372	0.02635	0.02898	0.03160	0.03685	0.03948
	2500	0.02160	0.02207	0.02262	0.02326	0.02398	0.02592	0.02785	0.03169	0.03365
	3000	0.02151	0.02196	0.02249	0.02307	0.02372	0.02445	0.02588	0.02905	0.03071
	3500	0 02144	0.02185	0.02235	0.02292	0.02355	0.02422	0.02497	0.02736	0.02865
	4000	0.02138	0.02177	0.02224	0.02278	0.02338	0.02402	0.02471	0.02639	0.02745
	4500	0.02132	0.02169	0.02214	0.02265	0.02322	0.02383	0.02449	0.02594	0.02692
250	Bubble point	(758) 0.02291	(1238) 0.02340	(1732) 0.02392	(2225) 0.02447	(2699) 0.02504	(3123) 0.02562	(3520) 0.02622	(4231) 0.02742	(4555) 0.02803
	600	0.02720	0.0396	0.0521	0.0645					
	700	0.02423	0.0347	0.0452	0.0556					
	800	0.02290	0.0311	0.0402	0.0493					
	1000	0.02284	0.0267	0.03390	0.04109	0.0483				
	1250	0.02276	0.02341	0.02885	0.03440	0.04000	0.0454			
	1500	0.02269	0.02330	0.02573	0.03016	0.03460	0.03904	0.0435		
	2000	0.02254	0.02315	0.02382	0.02573	0.02895	0.03215	0.03534	0.04165	
	2500	0.02239	0.02296	0.02359	0.02431	0.02586	0.02829	0.03072	0.03558	0.03800
	3000	0.02224	0.02280	0.02340	0.02408	0.02486	0.02603	0.02794	0.03174	0.03363
	3500	0.02210	0.02262	0.02320	0.02387	0.02461	0.02539	0.02628	0.02955	0.03118
	4000		0.02247	0.02304	0.02369	0.02439	0.02515	0.02593	0.02805	0.02960
	4500		0.02234	0.02288	0.02350	0.02416	0.02487	0.02561	0.02722	0.0282

[a] Bubble-point pressure, lb. per sq. inch.
[b] Specific volume, cu. ft. per pound.

TABLE 8.—*Specific Volumes and Compositions for Bubble-point Liquid*

Pressure, Lb. per Sq. In. Abs.	100°F.		190°F.		250°F.	
	Specific Volume, Cu. Ft. per Lb.	Weight Fraction × 10²	Specific Volume, Cu. Ft. per Lb.	Weight Fraction × 10²	Specific Volume, Cu. Ft. per Lb.	Weight Fraction × 10²
500	0.02089	0.09[a]				
600	0.02097	0.60	0.02201	0.00		
700	0.02106	1.07	0.02205	0.40		
800	0.02114	1.55	0.02215	0.80	0.02295	0.19
1000	0.02132	2.50	0.02235	1.62	0.02315	1.02
1250	0.02156	3.66	0.02261	2.64	0.02341	2.04
1500	0.02181	4.90	0.02287	3.66	0.02367	3 06
2000	0.02242	7 52	0.02341	5.80	0.02421	5 06
2500	0.02321	10.45	0.02399	8.00	0.02480	7.14
3000	0.02417	13.62	0.02466	10.45	0.02544	9.40
3500	0.02540	17.00	0.02538	13.03	0.02619	11.90
4000	(0.0270)[b]	(20.5)	0.02621	15 70	0.02700	14.65
4500		(24.1)	0.02720	18.55	0.02792	17.64

[a] Weight fraction trap-gas sample.
[b] Figures in parenthesis are extrapolated.

the specific volumes for mixtures with weight fractions of the trap-gas sample below 0.08 do not involve uncertainties greater than 1 per cent, while mixtures containing greater amounts of gas may involve somewhat larger uncertainties. The behavior of bubble-point liquid for a system made up of mixtures of varying proportions of the trap-liquid and trap-gas samples is recorded in Table 8. It is believed that the uncertainty in the specific volume is not more than 0.5 per cent and the compositions are known within 1 per cent at pressures below 2000 lb. per sq. in. Above this value the appearance of a plastic phase rendered the strict attainment of equilibrium difficult, thereby increasing the uncertainty somewhat.

TABLE 9.—*Formation Volumes of Mixtures of Trap Samples*

Temperature, Deg. F.	Pressure, Lb. per Sq. In. Abs.	Gas-oil Ratio[a]								
		473.96	612.80	757.73	908.5	1065.7	1229.8	1401.0	1767.4	1964.1
		(480)[b]	(895)	(1315)	(1715)	(2085)	(2427)	(2750)	(3355)	(3645)
100	Bubble point	1.304[c]	1.353	1.406	1.463	1.528	1.598	1.676	1.855	1.96
	600	1.302	1.726	2.328	2.955	3.611	4.286	4.967		
	700	1.301	1.547	2.048	2.571	3.123	3.691	4.283	5.582	6.297
	800	1.300	1.433	1.868	2.317	2.785	3.265	3.761	4.863	5.463
	1000	1.298	1.350	1.611	1.951	2.307	2.677	3.065	3.921	4.401
	1250	1.295	1.347	1.436	1.697	1.973	2.249	2.541	3.173	3.507
	1500	1.292	1.343	1.402	1.542	1.761	1.990	2.232	2.745	3.016
	2000	1.286	1.341	1.395	1.457	1.531	1.714	1.880	2.233	2.422
	2500	1.281	1.333	1.388	1.451	1.521	1.596	1.720	1.990	2.134
	3000	1.274	1.326	1.382	1.443	1.513	1.585	1.666	1.864	1.973
	3500	1.269	1.319	1.376	1.437	1.505	1.576	1.656	1.847	
	4000	1.262	1.313	1.370	1.431	1.498	1.568	1.645	1.833	
		(600)	(1095)	(1580)	(2045)	(2500)	(2901)	(3300)	(4055)	(4405)
190	Bubble point	1.375	1.429	1.494	1.557	1.626	1.697	1.776	1.950	2.049
	600	1.467	2.13	2.93	3.76	4.64	5.55	6.49		
	700	1.404	1.90	2.57	3.27	3.99	4.76	5.55	7.25	
	800	1.373	1.72	2.28	2.86	3.47	4.11	4.78	6.18	
	1000	1.369	1.503	1.95	2.411	2.896	3.40	3.94	5.07	5.68
	1250	1.366	1.429	1.70	2.037	2.403	2.799	3.21	4.08	4.55
	1500	1.363	1.424	1.531	1.806	2.097	2.400	2.717	3.42	3.78
	2000	1.356	1.412	1.481	1.574	1.786	2.007	2.238	2.732	2.995
	2500	1.349	1.404	1.471	1.543	1.626	1.795	1.972	2.349	2.553
	3000	1.344	1.397	1.462	1.533	1.612	1.695	1.833	2.156	2.323
	3500	1.339	1.390	1.453	1.521	1.597	1.678	1.768	2.028	2.174
	4000	1.336	1.387	1.446	1.512	1.585	1.663	1.750	1.956	2.083
	4500	1.332	1.382	1.440	1.503	1.574	1.650	1.734	1.923	2.043
		(758)	(1238)	(1732)	(2225)	(2699)	(3123)	(3520)	(4231)	(4555)
250	Bubble point	1.431	1.490	1.555	1.624	1.698	1.775	1.857	2.033	2.127
	600	1.699	2.52	3.39	4.28					
	700	1.514	2.21	2.94	3.69					
	800	1.431	1.98	2.61	3.27					
	1000	1.427	1.70	2.204	2.727	3.28				
	1250	1.422	1.491	1.876	2.283	2.712	3.14			
	1500	1.417	1.484	1.673	2.001	2.346	2.704	3.08		
	2000	1.408	1.475	1.549	1.707	1.963	2.226	2.503	3.09	
	2500	1.399	1.462	1.534	1.613	1.753	1.959	2.176	2.638	2.883
	3000	1.389	1.452	1.521	1.598	1.685	1.803	1.979	2.353	2.552
	3500	1.381	1.441	1.508	1.584	1.668	1.758	1.861	2.191	2.366
	4000		1.431	1.498	1.572	1.654	1.742	1.836	2.079	2.246
	4500		1.423	1.488	1.559	1.638	1.722	1.814	2.018	2.132

[a] Gas-oil ratio expressed as cubic feet per barrel of pentane-free oil, measured at 60°F. and 14.73 lb. per sq. inch.
[b] Bubble-point pressure, lb. per sq. inch.
[c] Formation volume, volume per unit volume of pentane-free oil, measured at 60°F. and 14.73 lb. per sq. inch.

FORMATION VOLUME

The formation volume of a hydrocarbon mixture may be defined as the volume occupied by the hydrocarbons associated with a unit volume of liquid production as measured under surface standard conditions.* This definition results in a variation

* Surface standard conditions are taken at 60°F. and 14.73 lb. per sq. in. absolute.

in the formation volume of a particular hydrocarbon mixture with the method of production since the separation into "oil" and "gas" may vary. For this reason the formation volume has been defined for present purposes as the volume, under the prescribed conditions, of the hydrocarbons that are associated with a unit volume of pentane-free liquid as measured under surface standard conditions. Throughout the remaining part of this discussion the term "gas" is employed to describe all of

TABLE 10.—*Formation Volume and Gas-oil for Bubble-point Liquid*

Pressure Lb. per Sq. In. Abs.	100°F.		190°F.		250°F.	
	Gas-oil Ratio	Formation Volume	Gas-oil Ratio	Formation Volume	Gas-oil Ratio	Formation Volume
500	478[a]	1.306[b]				
600	513	1.318	473	1.375		
700	545	1.330	499	1.382		
800	579	1.341	526	1.395	485	1.436
1000	647	1.365	584	1.418	542	1.461
1250	730	1.396	655	1.449	614	1.492
1500	823	1.430	730	1.481	687	1.524
2000	1025	1.512	891	1.550	835	1.591
2500	1267	1.615	1064	1.626	995	1.666
3000	1541	1.743	1267	1.716	1178	1.751
3500	1864	1.904	1488	1.818	1390	1.852
4000			1736	1.936	1635	1.969
4500			2020	(2.076)[c]	1928	(2.109)

[a] Gas-oil ratio expressed as cubic feet per barrel of pentane-free oil, measured at 60°F. and 14.73 lb. per sq. inch.
[b] Formation volume, volume per unit volume of pentane-free oil under standard conditions, 60°F. and 14.73 lb. per sq. inch.
[c] Figures in parenthesis are extrapolated.

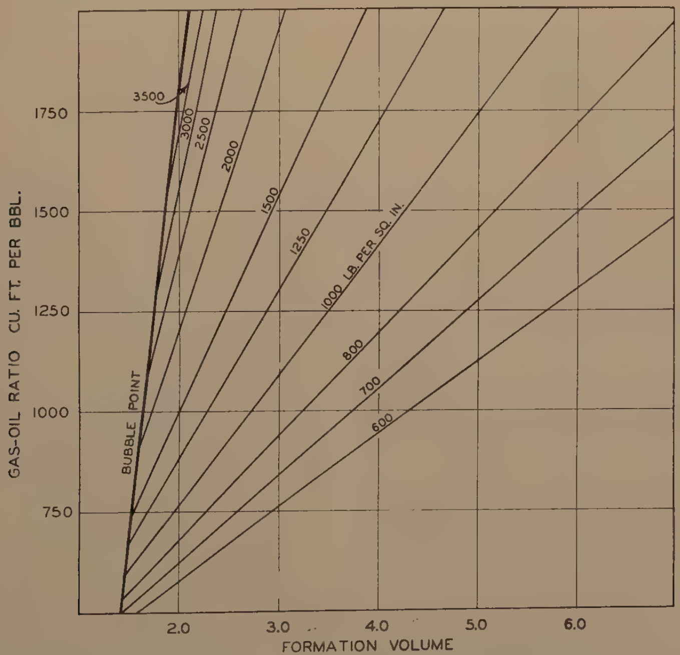

FIG. 4.—EFFECT OF GAS-OIL RATIO UPON FORMATION VOLUME AT 190°F.

the n-pentane and the lighter hydrocarbons while the term "oil" refers to the heavier materials. This arbitrary classification of the hydrocarbons does not necessarily agree with the separations occurring in normal than n-pentane), both being measured at surface standard conditions. Values of the gas-oil ratio for each of the mixtures reported have been computed on this basis and are recorded in a part of Table 6.

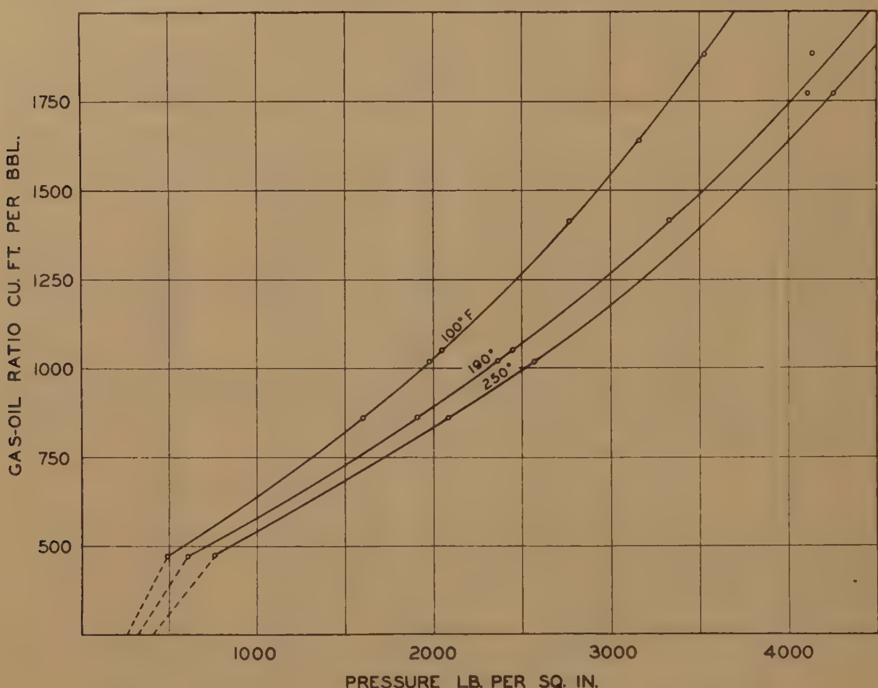

FIG. 5.—EFFECT OF GAS-OIL RATIO UPON BUBBLE-POINT PRESSURES.

production practice, but the procedure has the advantage that the terms oil and gas are given definite quantitative significance.

For many purposes it is convenient to employ the gas-oil ratio as an approximate measure of the composition of a naturally occurring hydrocarbon mixture. The exact value of this quantity as measured in the field for any particular total composition of hydrocarbons depends to some extent upon the conditions of separation that affect the amounts and compositions of gas and oil. For this reason the gas-oil ratio used here is defined as the number of cubic feet of gas (n-pentane and light hydrocarbons) as measured at surface standard conditions that is associated with one barrel of oil (the hydrocarbons heavier

The formation volume as defined above for a mixture of hydrocarbons is related to the specific volume by means of the following expression

$$v = V/V_{to}n_l = V/0.01891n_l \qquad [2]$$

Equation 2 is applicable to both the one-phase and two-phase regions and permits the calculation of the formation volume for any state where the specific volume and composition are known. The formation volumes for the mixtures recorded in Table 7 have been calculated in accordance with equation 2 and are tabulated in Table 9. The uncertainty in these values is comparable to that of the specific volume upon which they were based.

The influence of gas-oil ratio upon formation volume under isobaric conditions at

190°F. is shown in Fig. 4. The behavior in the condensed liquid region has not been indicated because of the small variations encountered. The nearly linear relationship between gas-oil ratio and formation volume depicted in the figure apparently is typical of most naturally occurring hydrocarbon mixtures, even at rather elevated pressures. The effect of gas-oil ratio upon bubble-point pressure is presented in Fig. 5. In general, the experimental values indicate a satisfactory precision of measurement; however, at pressures of more than 4000 lb. per sq. in. the disagreement of one or two experimental points from the smooth curve was large. It is believed that this discrepancy was due to difficulty in attaining phase equilibrium when a relatively large quantity of coalesced bitumen was present. The dotted curves in the lower left-hand portion of the figure indicate in a general way the relationship of bubble-point pressure and gas-oil ratio when gaseous material is removed from the trap-liquid sample. It should be emphasized that the composition of the gas in the mixture changes with gas-oil ratio. In general, the gas becomes progressively richer in methane as the gas-oil ratio is increased.

The gas-oil ratio and formation volume of bubble-point liquid has been recorded as a function of pressure for 100°, 190° and 250°F. in Table 10. These data involve approximately the same uncertainties as were reported for Table 8. The lower limit of the pressures recorded in this table was determined by the bubble-point pressure of the trap-liquid sample at each temperature.

Comparison of Observed and Calculated Values

It is advantageous to be able to predict the volumetric behavior of naturally occurring hydrocarbon mixtures in terms of the prevailing pressure, temperature and composition of the material. Although the analyses reported are not complete, they are sufficient to permit the estimation of the behavior of the trap samples and their mixtures from the generalized relationships available at present.

Several methods have been proposed for estimating the volumetric behavior of natural gases.[5,9,10,11] The application of these methods to the prediction of the volumetric behavior of the trap-gas sample yielded results in agreement with the data presented in Table 4 within 2 per cent at pressures below 3000 lb. per sq. in. The correlation presented by Smith[10] gave the best agreement with the experimental values at the higher pressures. Comparisons of this nature have indicated that the volumetric behavior of natural gases may be predicted with reasonable accuracy as long as the states under consideration are appreciably removed from the heterogeneous region.

Some information is available concerning the partial volumetric behavior of the lighter hydrocarbons in the liquid phase.[4] A comparison of experimentally determined values for the specific volumes of the liquid phase of the trap-liquid sample and of mixtures of the two trap samples with values predicted from composition and partial volumes indicated an agreement of approximately 2.5 per cent with a few isolated values disagreeing by as much as 3.1 per cent. The bubble-point pressures of the trap-liquid sample and of mixtures of the trap samples may be estimated from equilibrium constants[2,3] for the more important components. A comparison of the predicted bubble-point pressures and those determined experimentally yielded agreements varying between 3 and 1 per cent. Fortuitously, the best agreement was obtained at the highest weight fraction of the trap-gas sample.

Although it is possible to predict the formation volume of a heterogeneous mixture by the method discussed above, it is often advantageous to employ a more empirical approach in connection with hydrocarbon mixtures for which some

experimental information is available. If it is assumed that the isobaric, isothermal relationship between the specific volume and the weight fraction of gas is linear throughout the two-phase region, and if the discontinuity in the first derivative of this relationship at dew point is neglected, it is possible to estimate the formation volume in the two-phase region from experimental information concerning the behavior of bubble-point liquid and the trap-gas sample.

On the basis of the foregoing assumptions a relationship between the pertinent variables may be established. The volume of the hydrocarbon mixture associated with a unit volume of oil as measured under standard conditions may be considered as made up of the volume of the liquid phase associated with this unit volume of oil (i.e., the formation volume of bubble-point liquid) and that of the remaining gas phase. The volume at the temperature and pressure in question corresponding to a cubic foot of gas measured under standard conditions is given by the ratio P_STZ/PT_ST_S. However, all of the gas associated with the production is not in the gas phase at the state under consideration and on the basis of the above mentioned assumptions the quantity can be established from the difference between the surface gas-oil ratio and the gas-oil ratio of bubble-point liquid under the conditions in question. Therefore, the relationship between the formation volume of a heterogeneous mixture and the behavior of the bubble-point liquid and of the trap-gas sample becomes:

$$v = v_b + 0.1781 \frac{P_STZ}{PT_SZ_S}(r - r_b) = v_b + 0.005062 \frac{TZ}{P}(r - r_b) \quad [3]$$

It should be realized that equation 3 is approximate, since it involves a number of assumptions concerning the volumetric and phase behavior of the system. However, it is sufficiently descriptive of actual behavior to make it of engineering value, especially at low pressures. A comparison of the observed formation volumes and those calculated from this relation indicates a maximum disagreement of about 3.0 per cent and an average deviation of 1.8 per cent. It is believed that equation 3 may be employed with nearly equal accuracy to gas-oil ratios higher than those covered in this experimental investigation.

Acknowledgment

This experimental work was sponsored by the Union Oil Company of California, and the authors wish to express their appreciation for financial assistance and permission to publish these results. The assistance of Mr. H. C. Pyle in connection with the procurement of the samples and of the analyses of the hydrocarbon material was especially helpful. Donald A. Emberson assisted in the preparation of the figures.

Nomenclature

b, specific gas constant (per pound).
M_a, average molecular weight.
n, weight fraction.
P, pressure, lb. per sq. in. absolute.
r, gas-oil ratio, cu. ft. per barrel.
R, universal gas constant (per mol).
T, temperature, deg. R. (deg. F. abs.).
V, specific volume, cu. ft. per pound.
v, formation volume.
Z, compressibility factor ($Z = PVM_a/RT$) $= PV/bT$).
Subscript o signifies infinite attenuation.
Subscript S signifies surface standard conditions, 60.0°F. (519.7°R.) and 14.73 lb. per sq. in. absolute.
Subscript b signifies bubble-point condition.
Subscript l signifies pentane-free liquid or "oil."

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DISCUSSION

E. O. Bennett,* Ponca City, Okla.—The curves of Fig. 1 showing the compressibility for trap-gas samples are interesting and give valuable information for the computation of reserves in the formation, and also for calculating the formation pressure from known well-head shut-in pressures. These curves are similar to a set obtained from a high-pressure well in the Lake Arthur field near Jennings, La.

It is interesting to know that deviations calculated by Dr. George G. Brown's pseudocritical temperature and pressure method for methane check closely the actual values found in field tests. It appears that the pseudocritical curves may be used for most practical applications.

B. H. Sage and H. H. Reamer (authors' reply).—It has been our experience that the pseudocritical concept as applied to natural gases usually yields results of satisfactory engineering accuracy. However, rather large discrepancies amounting to as much as 10 per cent are encountered in the neighborhood of dew point at elevated pressures. It is my understanding that although the pseudocritical concept has been widely applied by Dr. Brown, it was first proposed by W. B. Kay[12] in connection with his experimental studies of the volumetric behavior of hydrocarbon fluids.

D. G. Kingman,* Taft, Calif.—From the occurrence of "bitumen" in your test apparatus, would you hazard an opinion as to where the material might accumulate in the well bore?

B. H. Sage (author's reply).—At this time I have insufficient factual information to permit any conclusions to be drawn as to the point of accumulation of the semiplastic material in production equipment.

* Continental Oil Co.

[12] W. B. Kay: *Ind. and Eng. Chem.* (1936) **28**, 1014.

* General Petroleum Corporation of California.

Equilibrium Constants for Hydrocarbons in Absorption Oil

By C. E. Webber*

(Tulsa Meeting, October 1940)

The economical recovery of the valuable constituents from the effluent of gas-condensate wells has developed into a problem of balancing the cost of recovery against the cost of compressing the residual gas back into the formation. A possible method of extracting the gasoline and distillate from the natural gas is by oil absorption at high pressures. In order to design and evaluate an absorption plant, fundamental data on the composition of the coexisting hydrocarbon vapor and liquid phases at various temperatures and pressures are essential.

A review of the literature indicated that the necessary data for the design of such plants are lacking. The nearest approach to desired published data is that of Katz and Hackmuth,[2] who experimentally determined the composition of the coexisting vapor and liquid phases in a natural gas-crude oil system at pressures up to 3000 lb. per sq. in. and at temperatures from 40° to 200°F.

This paper presents the results of the experimental determination of the equilibrium distribution of the hydrocarbons methane through hexane between natural gas and a typical absorber oil. The ranges of temperature and pressure chosen were from 33° to 180°F. and from 100 to 5000 lb. per sq. inch.

Materials

The absorber oil was a typical naturally occurring, straw-colored distillate that had previously been steam-distilled to an initial boiling point of 300°F. The physical and chemical properties, including the results of an Engler distillation, are presented in Table 1. A large volume of this oil was obtained and it was used throughout the complete set of experiments.

Table 1.—*Properties of the Absorption Oil*

Gravity	32.5° A.P.I.
Molecular weight by benzene freezing-point depression	183
Viscosity, poises: at 100°F	0.0280
At 200°F	0.0102

Composition,[a] Per Cent

Aromatics	24.0	Naphthenes	36.7
Unsaturates	0.3	Paraffins	39.0

Engler Distillation

Per Cent	Deg. F.	Per Cent	Deg. F.
Initial boiling point	300	60	523
5	402	70	538
10	421	80	557
20	462	90	570
30	480	95	623
40	497	97.7	650
50	511		

Residue, 2.0 per cent; loss, 0.3 per cent.
[a] See reference 1.

The *n*-hexane was obtained from the Ohio Chemical and Manufacturing Co., Cleveland, Ohio. This liquid had a boiling range of from 149° to 152.6°F., with a density of 0.667 at 60°F. and a molecular weight of 85 by benzene freezing-point depression. The propane, isobutane, *n*-butane, isopentane and *n*-pentane were obtained from the Philgas Department of the Phillips Petroleum Co. Certified analyses of these compounds showed their purity to be in excess of 99.5 per cent and they were not further purified.

Manuscript received at the office of the Institute Aug. 12, 1940. Issued as T.P. 1252 in Petroleum Technology, November 1940.
* Humble Oil and Refining Co., Houston, Texas.
[2] References are at the end of the paper.

The methane and ethane were obtained from natural gas that was passed at 2000-lb. pressure through activated charcoal and calcium chloride to remove all moisture and heavier hydrocarbons. The average of several analyses of this stripped gas was methane, 95 per cent; ethane, 3 per cent; and propane, 2 per cent.

Apparatus

Equilibrium between the gas and liquid phases was reached in a cell of approximately 1000 ml. capacity, constructed from 4-in. double extra heavy seamless steel pipe. The ends of this cell were solid pieces screwed into the pipe and welded. A ⅛-in. nipple extended from each end of the cell. It was tested to 8000 lb. per sq. in. before being used. The complete apparatus is shown in Fig. 1.

On the sides of the cell were welded two arms, which extended out to slide through a frame mounting, permitting the cell to be rotated lengthwise for agitating the hydrocarbon mixture. The inside was reamed smooth and the ends were tapered to ensure complete drainage. The cell and rocker frame were placed in a large constant-temperature bath constructed of 12-gauge sheet iron, insulated with 2-in. magnesia blocks and mounted on rollers. The bath was equipped with a motor-driven stirrer, a thermoregulator and an electric heater. The 33°F. temperatures were maintained by merely filling the bath with crushed ice and water. The bath was kept at constant temperature (±0.5°F.) at all times during the experiments.

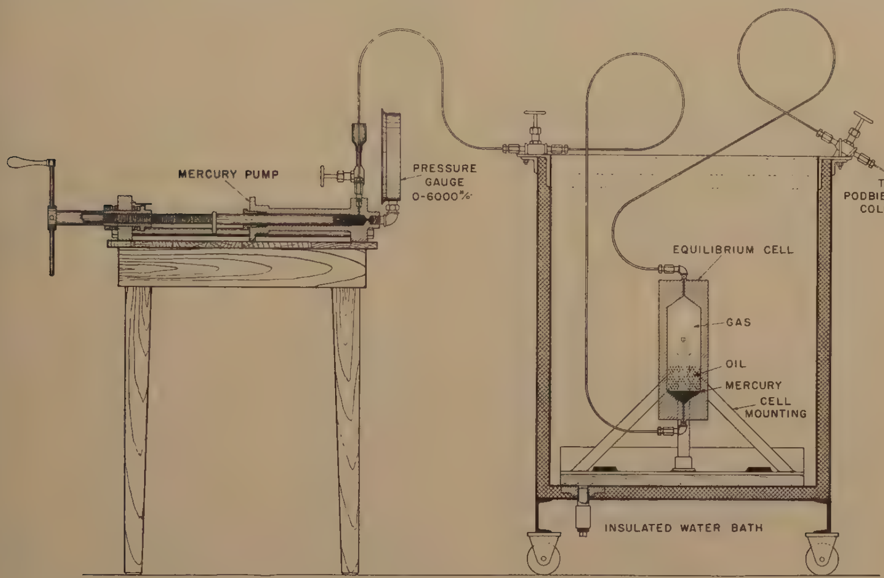

Fig. 1.—Apparatus for determination of vaporization equilibrium constants.

Two ⅛-in. stainless-steel needle valves mounted on the bath were connected to the ends of the equilibrium cell with short lengths of ⅛-in. outside diameter, 1⁄16-in. inside diameter stainless-steel tubing. One valve was used to regulate the rate of flow of either gas or liquid to the Podbielniak column, and the other was connected to a mercury pump.

A piston-type mercury pump was used for reaching and maintaining pressures. On it was mounted a 0 to 6000-lb. Heise Bourdon-tube gauge, graduated in 10-lb. divisions. This gauge was previously calibrated

against a dead-weight tester. A 0 to 150-lb. gauge was substituted for the Heise gauge during the determinations at 114.7 lb. per sq. in. absolute.

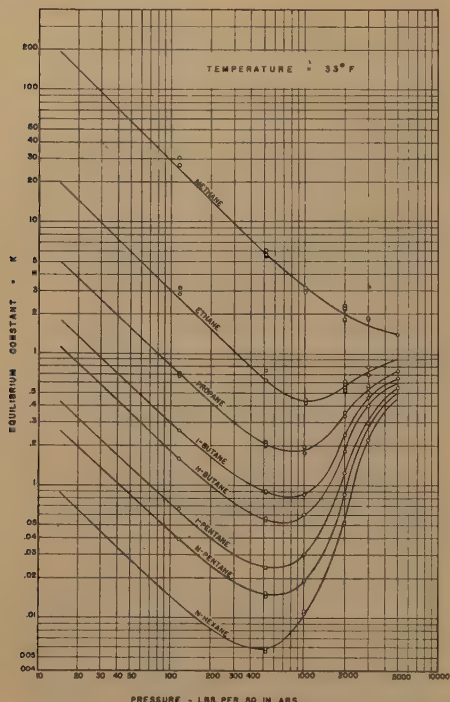

FIG. 2.—EXPERIMENTAL RESULTS, 33°F.

The samples were analyzed in an automatic Podbielniak fractionating column. A small topping column having a still of 200 ml. capacity and a fractionating section approximately 12 in. high, containing a spiral of 15-gauge copper wire, was installed between the equilibrium cell and the Podbielniak column for analyzing liquids. A small water condenser was connected to the top of the fractionating section of the topping still, and a thermometer extended down into the top of this column.

For analyzing gases at the higher pressures, a small trap for preventing the heavier components from entering and freezing in the side arm of the Podbielniak still was installed between the still and the equilibrium cell.

Experimental Technique

The equilibrium cell was evacuated, and the desired amount of absorption oil (a fresh sample for each determination) and liquid hydrocarbons—pentanes and hexane—were sucked into the cell. The butanes and lighter gases were then charged from their storage vessels to a predetermined pressure in the cell. The last gas to be charged in each case was the stripped natural gas from the 2000-lb. storage cylinder. Prior to building up the final desired pressure by mercury injection, the bath temperature was adjusted to the proper level.

During the first series of experiments (at 100°F.) the stripped gas and a single other component only were charged into the cell with the oil. This procedure involved more analyses than time would allow, and, in the later experiments, several hydrocarbons were simultaneously charged into the cell with the oil. However, analytical accuracy was still retained by avoiding the simultaneous addirion of any two adjacent hydrocarbons with close boiling points.

The cell was rocked back and forth until no pressure drop occurred, indicating attainment of equilibrium between the coexisting phases. Rocking was then continued for a period of 15 to 30 min., to further ensure complete equilibrium within the cell.

The cell was then turned to a vertical position and the fluids allowed to drain, so that the materials were segregated into three layers: gas, oil and mercury. The gas was displaced from the cell to the Podbielniak column, constant pressure being maintained during the displacement by forcing mercury into the cell as the gas was withdrawn from the top. When sufficient gas had been charged to the column, the valve was shut, and by cooling the still of the column, a vacuum was applied on the small trap containing any condensed liquid. The application of heat to the trap expelled all of the hydrocarbons, except absorption

TABLE 2.—*Phase Analyses at 33°F.*

Hydrocarbon	Pressure 114.7 Lb. per Sq. In. Abs.						Pressure 514.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	83.70	3.11	26.90	83.72	2.72	30.60	94.86	16.99	5.57	93.25	17.02	5.47
Ethane	6.44	2.26[a]	2.85	5.41	1.69[a]	3.19	1.50	2.00	0.75	1.46	2.31	0.63
Propane	5.10	7.56	0.674	7.20	10.28	0.70	1.79	8.38	0.214	3.29	16.44	0.20
i-butane	3.50	13.40	0.26				1.45	15.88	0.0914			
n-butane				2.94	18.50	0.159				1.75	30.73	0.057
i-pentane	1.26	18.74	0.067				0.30	12.39	0.0242			
n-pentane				0.73	18.87	0.039				0.17	11.45	0.0146
n-hexane							0.10	16.86	0.0059	0.08[a]	8.60	
Oil		54.93			47.94			27.50			13.45	
Sp. gr.		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 514.7 Lb. per Sq. In. Abs.						Pressure 1014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	94.95	17.64	5.37	91.91	15.10	6.08	95.74	30.32	3.16	95.87	32.81	2.92
Ethane	1.11	0.90[a]		2.29	2.21[a]		1.37	3.24	0.422	1.11	2.45	0.45
Propane	2.68	12.98	0.206	4.29	19.60	0.214	1.06	5.33	0.199	1.42	7.96	0.179
i-butane				1.51	16.94	0.089	1.36	15.73	0.086			
n-butane	0.91	16.56	0.055							1.32	21.63	0.061
i-pentane							0.32	10.22	0.031			
n-pentane	0.25	16.23	0.0154							0.18	9.47	0.019
n-hexane	0.10	18.01	0.0056				0.15	13.16	0.0114	0.10	9.95	0.010
Oil		17.68			46.15			22.00			15.73	
Sp. gr.		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 2014.7 Lb. per Sq. In. Abs.											
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	92.55	40.43	2.29	92.26	42.52	2.17	89.79	49.83	1.80	90.40	49.45	1.82
Ethane	3.39	5.77	0.59	2.81	5.05	0.56	2.16	4.27	0.506	2.18	4.24	0.513
Propane	2.64	7.81	0.338	2.56	7.16	0.358	3.55	7.70	0.460	3.39	7.82	0.434
i-butane				1.38	5.69	0.242	2.82	9.33	0.302	2.22	8.65	0.257
n-butane	1.42	8.35	0.170									
i-pentane				0.99	7.82	0.127	0.97	6.10	0.159	1.00	6.31	0.161
n-pentane												
n-hexane							0.71	7.60	0.093	0.81	8.25	0.098
Oil		37.64			31.76			15.17			15.28	
Sp. gr.		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

[a] Inaccurate separation.

TABLE 2.—(*Continued*)

Hydrocarbon	Pressure 2015.7 Lb. per Sq. In. Abs.						Pressure 3014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		*K*	Composition, Mol Per Cent		*K*	Composition, Mol Per Cent		*K*	Composition, Mol Per Cent		*K*
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	93.89	41.98	2.23	{ 89.46	48.66		83.81	56.94	1.47	89.00	52.59	1.69
Ethane	3.39	5.45	0.62		3.59		2.61	2.96[a]		2.82	4.07	0.69
Propane	1.64	5.76	0.28	5.67	12.56	0.451	6.37	9.91	0.64	4.26	7.76	0.55
i-butane							3.33	6.06	0.55			
n-butane				3.63	12.72	0.285				2.88	7.12	0.405
i-pentane							1.86	4.29	0.434			
n-pentane	0.62	7.20	0.086	1.24	6.58	0.173						
n-hexane	0.46	8.63	0.053		15.89		1.73	5.12	0.338	1.04	4.64	0.220
Oil		30.98					0.29	14.72			23.82	
Sp. gr.		0.8628			0.8628		0.7180	0.8640			0.8640	
Mol. wt.		183			183		128	186			186	

Hydrocarbon	Pressure 3014.7 Lb. per Sq. In. Abs.						Pressure 5014.7 Lb. per Sq. In. Abs.		
	Composition, Mol Per Cent		*K*	Composition, Mol Per Cent		*K*	Composition, Mol Per Cent		*K*
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	90.10	50.21	1.80	92.70	50.92	1.82	86.03	61.47	1.40
Ethane	2.98	4.33	0.69	3.01	3.80	0.79	3.75	3.86[a]	
Propane	3.64	6.39	0.57	2.70	5.27	0.51	4.44	6.08	0.73
i-butane	1.56	3.61	0.432				2.29	3.51	0.65
n-butane									
i-Pentane	1.51	5.12	0.296				1.81	3.31	0.55
n-Pentane				1.36	6.63	0.205			
n-hexane									
Oil	0.21	30.34		0.23	33.38		1.68	21.77	
Sp. gr.	0.8230	0.8640		0.784	0.8640		0.8400	0.8700	
Mol. wt.	159	186		130	186		168	200	

[a] Inaccurate separation.

oil, that might have collected. The volume, specific gravity and molecular weight were determined on this residual liquid after completion of the hydrocarbon analysis.

To reduce the necessity of making so many determinations of molecular weight, a method of estimating them from the specific gravities was employed. Three 400-ml. portions of absorption oil were topped—10 ml. from the first, 20 ml. from the second and 30 ml. from the third—and the specific gravity and molecular weight were determined on each overhead fraction. From a curve of molecular weight versus specific gravity, the molecular weight of the liquid in question was estimated.

After completion of the gas analysis, any excess gas remaining in the equilibrium cell was displaced at constant pressure and discarded. The oil was then charged into the topping still, the volume charged depending upon its composition. The topping still retained all of the oil and some of the dissolved gases. The liquid was heated and refluxed, driving the hexane and lighter fractions over into the Podbielniak still. It was found that a temperature of 220°F. was sufficient to ensure complete denuding of the absorption oil.

Specific gravities and molecular weights were determined on the oil samples only when an appreciable portion of the oil had

TABLE 3.—*Phase Analyses at 100°F.*

Hydrocarbon	Pressure 114.7 Lb. per Sq. In. Abs.									Pressure 514.7 Lb. per Sq. In. Abs.		
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	71.87	2.51	28.6	74.98	2.33	32.1	72.50	} 2.52		87.78	12.82	6.85
Ethane	7.13	0.34[a]		6.90	0.72[a]		6.17			1.14	0.59[a]	
Propane	10.44	6.56	1.59	7.84	4.71	1.66	10.96	7.01	1.56	5.25	11.25	0.467
i-butane	4.80	5.94	0.807				7.09	8.94	0.79			
n-butane				6.97	13.50	0.516				4.86	29.48	0.165
i-pentane	4.28	18.61	0.229				2.31	11.14	0.207	0.82	11.66	0.07
n-pentane				3.31	19.25	0.172						
n-hexane	1.48	22.57	0.065				0.97	15.88	0.067	0.15[a]	11.69	
Oil		43.47			59.49			54.51			22.51	
Sp. gr.		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 1014.7 Lb. per Sq. In. Abs.											
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	98.16	20.63	4.76	95.52	25.98	3.67	91.77	22.08	4.16	95.45	23.24	4.11
Ethane	1.74	1.74	1.00	1.81	2.19	0.83	2.37	2.71	0.87	1.92	2.67	0.72
Propane	0.10[a]	0.48		0.15[a]	0.73		0.18[a]	0.16		0.09[a]	0.25	
i-butane												
n-butane							5.68	37.97	0.15			
i-pentane										2.54	37.27	0.068
n-pentane				2.52	44.33	0.057						
n-hexane												
Oil		77.15			26.77			37.08			36.57	
Sp. gr		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 1014.7 Lb. per Sq. In. Abs.									Pressure 2014.7 Lb. per Sq. In. Abs.		
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	92.09	21.86	4.21	95.75	26.67	3.59	90.01	22.27	4.04	97.76	34.09	2.87
Ethane	2.25	2.92[a]		2.12	2.33	0.91	2.37	2.98	0.795	1.85	2.93	0.63
Propane	0.24[a]	0.40		0.23	0.39[a]		6.87	16.88	0.407	0.36[a]	1.26	
i-butane	5.42	29.04	0.187									
n-butane												
i-pentane				1.33	20.82	0.064						
n-pentane				0.57	25.64	0.022	0.75	29.01	0.026			
n-hexane												
Oil		45.78			24.15			28.86		0.03	61.72	
Sp. gr.		0.8628			0.8628			0.8628			0.8633	
Mol. wt.		183			183			183			183	

[a] Inaccurate separation.

TABLE 3.—(*Continued*)

Hydrocarbon	Pressure 2014.7 Lb. per Sq. In. Abs.											
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	95.13	41.73	2.28	92.15	37.52	2.46	93.82	39.06	2.40	90.76	36.82	2.46
Ethane	1.03[a]	2.75		3.27	4.11	0.80	2.44[a]	3.60		2.94[a]	3.73	
Propane	0.08[a]	0.29		0.42	0.98[a]		0.20[a]	0.53		0.50	1.16	0.43
i-butane										5.80	19.93	0.29
n-butane				4.16	18.99	0.22						
i-pentane							3.54	26.14	0.135			
n-pentane	3.76	32.06	0.117									
n-hexane												
Oil		23.17			38.40			30.67			38.36	
Sp. gr.		0.8633			0.8633			0.8633			0.8633	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 2014.7 Lb. per Sq. In. Abs.			Pressure 3014.7 Lb. per Sq. In. Abs.								
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	94.00	45.26	2.08	97.12	43.38	2.24	91.23	53.82	1.70	92.64	45.85	2.02
Ethane	2.32	2.80		2.50	3.92	0.63	2.29	3.05	0.75	2.54	3.21[a]	
Propane	0.41			0.24[a]	0.86		0.25[a]	0.42		0.29	0.20[a]	
i-butane												
n-butane										4.35	13.95	0.311
i-pentane	2.12	14.94	0.112									
n-pentane							6.13	21.89	0.28			
n-hexane	1.15	18.98	0.064									
Oil		18.02		0.14	51.84		0.10	20.82		0.18	36.79	
Sp. gr.		0.8639		0.7800	0.8639		0.7800	0.8639		0.7800	0.8639	
Mol. wt.		184		119	184		119	184		119	184	

Hydrocarbon	Pressure 3014.7 Lb. per Sq. In. Abs.									Pressure 4014.7 Lb. per Sq. In. Abs.		
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	90.47	49.13	1.84	91.48	46.66	1.96	93.11	60.32	1.54	96.11	51.25	1.87
Ethane	3.27[a]	4.78		2.35	3.00	0.783	2.27	1.99		3.14	4.90	0.64
Propane	0.69[a]	1.13		0.12[a]	0.50			0.73		0.45[a]	1.21	
i-butane				5.87	14.13	0.415						
n-butane												
i-pentane	5.33	19.20	0.28				2.43	11.54	0.21			
n-pentane												
n-hexane							2.05	10.62	0.193			
Oil	0.24	25.76		0.18	35.71		0.14	14.80		0.30	42.64	
Sp. gr.	0.7800	0.8639		0.7800	0.8639		0.7800	0.8639		0.8058	0.8649	
Mol. wt.	119	184		119	184		119	184		150	190	

[a] Inaccurate separation.

TABLE 3.—(*Continued*)

Hydrocarbon	Pressure 4014.7 Lb. per Sq. In. Abs.						Pressure 5014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	87.72	60.05	1.46	88.39	54.04	1.64	97.59	57.86	1.69	86.62	63.39	1.37
Ethane	3.35[a]	3.85		3.52	2.73[a]		1.69	2.52	0.67	3.98	4.73	0.84
Propane	0.76	0.98[a]		0.27	0.50[a]		0.18[a]	0.48		0.56	0.89[a]	
i-butane												
n-butane				7.20	15.89	0.453						
i-pentane												
n-pentane	7.15	17.10	0.42							7.04	12.35	0.57
n-hexane												
Oil	1.02	18.02		0.62	26.84		0.54	39.14		1.80	18.64	
Sp. gr.	0.8417	0.8649		0.8287	0.8649		0.7987	0.8644		0.7987	0.8700	
Mol. wt.	175	190		165	190		145	190		145	190	

Hydrocarbon	Pressure 5014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid	
Methane	86.22	63.48	1.36	85.76	60.48	1.42
Ethane	3.13	3.24[a]		2.71[a]	3.19	
Propane	1.02	1.30	0.785	0.62	0.59[a]	
i-butane				8.58	13.20	0.65
n-butane	7.65	12.31	0.621			
i-pentane						
n-pentane						
n-hexane						
Oil	1.98	19.67		2.33	22.54	
Sp. gr.	0.8297	0.8644		0.8385	0.8644	
Mol. wt.	167	190		168	190	

[a] Inaccurate separation.

entered the vapor phase. In all other cases, the specific gravity and molecular weight of the original oil were used in calculating the liquid analyses to mol per cent. In all determinations of molecular weight, three freezing-point depressions of benzene were measured at different concentrations of solute, and these three values were extrapolated to zero concentration of solute.

EXPERIMENTAL RESULTS

The hydrocarbon analyses of the coexisting gas and liquid phases are reported in Tables 2, 3 and 4. Sixty-one pairs of analyses are given in these tables, covering the complete range of temperature and pressure investigated. Together with the analyses are shown the vaporization equilibrium constants K^3, defined as mol fraction of a component in the vapor phase divided by mol fraction of the component in the liquid phase at equilibrium.

The errors that made it necessary to label many ethane determinations "Inaccurate" were due, mainly, to small volumes of ethane carried overhead in the Podbielniak column along with the methane. These volumes have a negligible effect upon the accuracy of the methane determinations, but cause appreciable errors in the ethane values because of the small amount of total ethane present.

TABLE 4.—*Phase Analyses at 180°F.*

Hydrocarbon	Pressure 114.7 Lb. per Sq. In. Abs.						Pressure 514.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	53.35	0.84[a]		49.87	1.12	44.50	69.81	9.12	7.65	73.86	8.73	8.45
Ethane	4.94	0.41[a]		4.42	0.45	9.81	2.32	0.66[a]		3.73	0.99[a]	
Propane	14.64	3.99	3.67	22.88	6.38	3.59	15.78	17.19	0.918	14.46	15.51	0.93
i-butane	14.46	7.74	1.86				7.19	14.03	0.512			
n-butane				17.38	12.35	1.41				6.01	14.86	0.404
i-pentane	8.02	11.14	0.72				3.28	12.93	0.253			
n-pentane				5.45	9.46	0.58				1.94	10.11	0.192
n-hexane	4.59	17.61	0.26				1.62	15.76	0.102			
Oil		58.27			70.24			30.31			49.80	
Sp. gr.		0.8628			0.8628			0.8628			0.8628	
Mol. wt.		183			183			183			183	

Hydrocarbon	Pressure 1014.7 Lb. per Sq. In. Abs.						Pressure 2014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	83.79	18.21	4.60	84 20	17.38	4.84	88.43	31.70	2.79	90.52	33.81	2.71
Ethane	3.74	2.49	1.50	2.55	1.41	1.81	3.88	3.46	1.12	2.37	2.28	1.04
Propane	5.80	8.60	0.675	5.69	8.51	0.669	3.80	6.77	0.562	2.48	5.10	0.49
i-butane	4.39	11.58	0.379				2.07	5.49	0.377			
n-butane				5.76	17.71	0.325				2.35	7.77	0.303
i-pentane	1.45	7.70	0.188				1.67	7.86	0.213			
n-pentane				1.80	10.88	0.165				1.23	6.99	0.176
n-hexane	0.83	9.40	0.088							1.05	9.30	0.113
Oil		42.02			44.11		0.15	44.72			34.75	
Sp. gr.		0.8628			0.8628		0.7600	0.8630			0.8628	
Mol. wt.		183			183		100	184			183	

Hydrocarbon	Pressure 3014.7 Lb. per Sq. In. Abs.						Pressure 5014.7 Lb. per Sq. In. Abs.					
	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K	Composition, Mol Per Cent		K
	Vapor	Liquid		Vapor	Liquid		Vapor	Liquid		Vapor	Liquid	
Methane	88.30	41.75	2.11	90.97	42 25	2.15	88.11	58.37	1.51	88.58	57.90	1.53
Ethane	4.23	4.55	0.932	3.37	3.20	1.09	4.01[a]	3.55		3.47	3.78	0.92
Propane	3.37	5.33	0.632	2.48	4.32	0.575	2.50	3.77	0.66	2.90	3.96	0.73
i-butane	1.74	3.62	0.480				1.46	2.50	0.58			
n-butane				1.65	4.81	0.343				1.80	3.30	0.54
i-pentane	1.11	3.81	0.291				1.44	2.97	0.48			
n-pentane				1.33	5.58	0.238				1.83	4.34	0.42
n-hexane	1.03	5.59	0.184				0.91	2.48	0.37			
Oil	0.22	35.35		0.20	39.84		1.57	26.36		1.42	26.72	
Sp. gr.	0.7800	0.8630		0.7800	0.8630		0.8371	0.8676		0.8365	0.8676	
Mol. wt	110	184		110	184		168	190		165	190	

[a] Inaccurate separation.

The experimental results are presented graphically in Figs. 2, 3 and 4, in which equilibrium constants are plotted against the absolute pressures. The portions of the hydrocarbons heavier than methane was found to pass through a minimum and thereafter to increase rapidly with increasing pressure. The pressures at the minimum

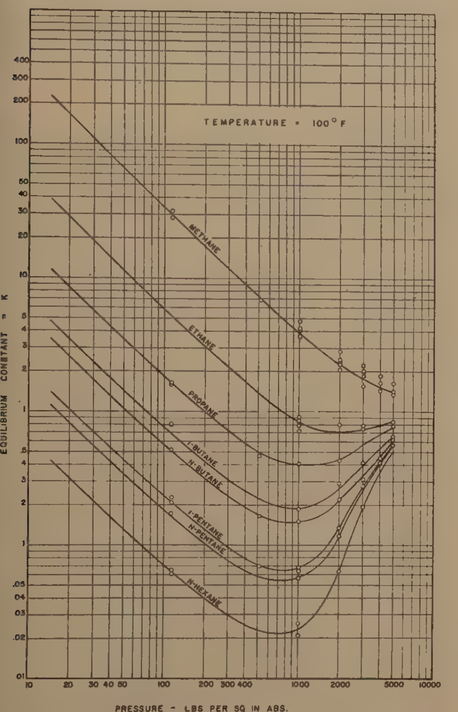

FIG. 3.—EXPERIMENTAL RESULTS, 100°F.

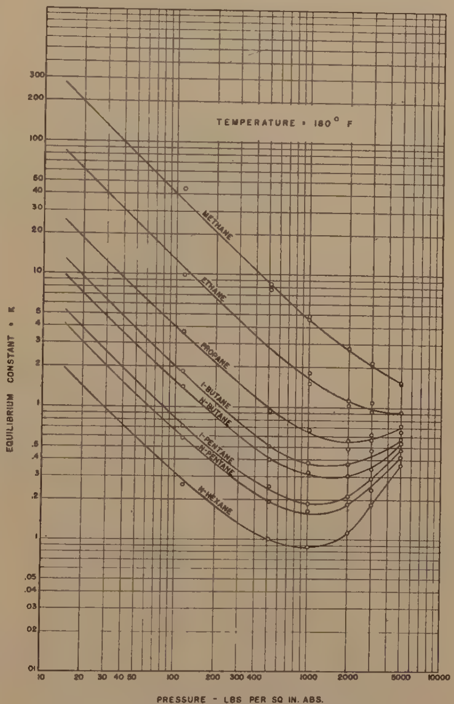

FIG. 4.—EXPERIMENTAL RESULTS, 180°F.

curves below 3000 lb. per sq. in. were prepared from large-scale smooth curves of the product of the equilibrium constant K and the absolute pressure P plotted against the absolute pressure P. The experimentally determined K values were dependent not only upon temperature and pressure, but also upon compositions of the mixtures involved, the effects of composition becoming increasingly pronounced at pressures above 3000 lb. per sq. in. Where the data permitted, the curves were drawn through the points that represented most nearly the compositions that might be expected in normal practice. In order to avoid confusion, some of the experimental points are omitted from the curves.

Each of the K-value curves for all of the K values varied with the temperatures; also for different components, being lower for the heavier components. At the higher pressures the K values for all of the components approached unity, but there was a significant reduction in the rate of approach at 5000 lb. per sq. inch.

The data checked very well with those of Katz and Hackmuth,[2] on a crude oil-natural gas system at pressures up to the minimum K values. As the pressure increased above this point, the divergence became pronounced.

The equilibrium constants for the absorber oil are not shown on the curves. However, appreciable quantities of the oil were found in the gas phase, particularly at pressures above 2000 lb. per sq. in. The

amount of oil in the vapor phase was dependent to a large degree upon the composition of the mixtures, being greater for the richer mixtures.

Conclusion

Vaporization equilibrium constants of methane through hexane in a typical absorption oil have been determined at temperatures from 33° to 180°F. and pressures from 100 to 5000 lb. per sq. in. These K values are considered to be suitable for any multicomponent hydrocarbon system up to 1500 lb. pressure. Above 3000 lb. per sq. in., the composition of the mixtures has a pronounced effect and care should be exercised in applying these values to systems that differ considerably from the one investigated.

Absorber operations seem feasible, even above 2000 lb. per sq. in., the optimum point with regard to oil circulation being at the pressure where the K values are at a minimum for the given temperature.

Acknowledgment

The writer wishes to express his appreciation to Mr. S. E. Buckley for his aid in outlining the experimental methods, to Messrs. L. H. Byrd, H. L. Hensley, C. B. Keagy and E. O. Staffel, for their aid in preparing and analyzing the samples, and to the Humble Oil and Refining Co. for permission to publish this work.

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DISCUSSION

D. L. Katz* and M. B. Standing,† Ann Arbor, Mich.—One point of particular interest is the reversed curvature of the equilibrium-constant curves as they rise toward unity at high pressures. The paper states that the composition of the system is a variable at high pressures and the curves are drawn through those compositions most nearly representing normal practice. The ratio of the gas to the absorber oil charged to the equilibrium cell was not given but it is presumed that these ratios were used in determining which points constituted normal practice.

An explanation of the reversed curvature is available from some recent measurements by the writers. Equilibrium constants of binary systems are known to converge to unity without reversing in direction. It is further known that the pressure of convergence at a given temperature is the critical pressure for the particular binary mixture that has its critical temperature at the temperature of the equilibrium.[4] The application of this principle to complex mixtures composed of two complex components such as an absorber oil and a natural gas would indicate that the convergence pressure for the equilibrium constants might be the critical pressure for the ratio of gas to oil which has its critical temperature at the equilibrium temperature. The data presented by Mr. Webber and recent experiments by the writers show that different mixtures of a gas and a liquid will have different convergence pressures for the equilibrium constants. Since only one ratio of gas to oil can have a given critical temperature; it should follow that all other mixtures when compressed will reach either a bubble or dew point before the vapor and liquid compositions become identical and the constants become unity.

Fig. 5 shows equilibrium-constant curves for 7000 cu. ft. of gas per barrel of oil and for 3500 cu. ft. of gas per barrel of the same oil both at 120°F. The highest pressure points measured were 8220 lb. and 5330 lb., respectively, and were on a smooth curve with the lower pressure points. As mentioned above, at some point between these pressures and the indicated convergence point, these systems would probably reach a single phase.

If Mr. Webber had used an increasing ratio of gas to oil as the pressure increased, as by using a constant liquid quantity in the cell, his points would have been on a series of curves that have increasing convergence pressures. A

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† University of Michigan.

[4] D. L. Katz and F. Kurata: Retrograde Condensation. *Ind. and Eng. Chem.* (1940) **32**, 817.

curve through the points could give the reversed curvature even though no reversal did occur for a constant composition system, as shown on Fig. 5.

critical pressure for the given mixture. Some of the curves shown have a point of inflection in the range of highest pressures, indicating that if a point of convergence may be expected it is at

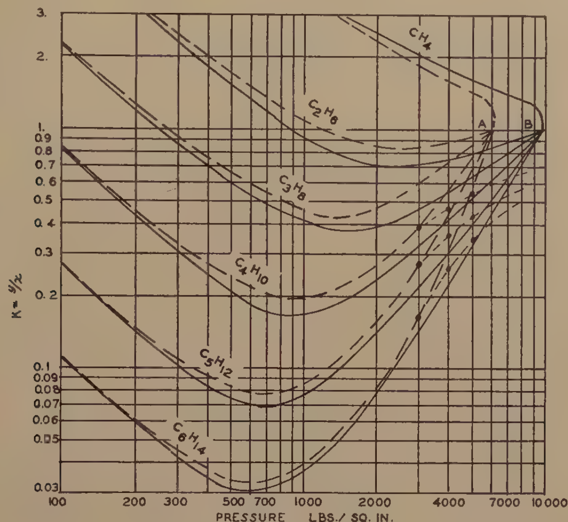

FIG. 5.—EFFECT OF COMPOSITION ON EQUILIBRIUM CONSTANTS NEAR THE CRITICAL PRESSURE.

This concept shows the need for the over-all composition of the system in batch determinations of the constants. At present, the pressure at which the constants converge appears to be slightly above the pressure at which the system reaches a single phase, but more data are required to give a complete understanding of this behavior near the critical conditions.

K. EILERTS,* Bartlesville, Okla.—The value of Mr. Webber's contribution to the published data on equilibrium constants is obvious and does not require elaboration, but I would like to ask Mr. Webber four questions to elicit further information:

Referring to Figs. 2, 3 and 4, the shape of the equilibrium constant curves at pressures above approximately 2000 lb. per sq. in. abs. is of particular interest. If identical mixtures of gas and adsorption oil were used in the determination of constants at a given temperature and variable pressure, and provided the given temperature was the critical temperature for the mixture, the values of constants for all components would be expected to approach unity at the pressures considerably above 5000 lb. per sq. in. abs. My first question is: Were mixtures of identical composition used at a given temperature, and if not were the compositions varied systematically with the pressure? As a second question: Were any physical tests performed at pressures above 5000 lb. per sq. in. abs. to determine whether a given mixture could be maintained in the single phase at the temperature of equilibrium constant determination?

It would not seem that the data just shown by Dr. Katz constitute conclusive proof that Mr. Webber's curves would have a common point if the mixtures used at a given temperature had been identical in composition. According to our concepts of the critical pressure and temperature of a mixture, Mr. Webber's curves at each temperature would, theoretically, have a common point only if the mixtures used at a given temperature were identical in composition and if it so happened that the experimental temperature were the critical temperature. The two sets of equilibrium constant curves shown by Dr. Katz (Fig. 5) were for two mixtures at the same temperature over a range of pressures. Although it is possible that one of the

* Associate Physical Chemist, U. S. Bureau of Mines.

sets of curves can have a common point at the given temperature, the other set could not, as the different mixtures necessarily must have different critical temperatures and pressures. In the curves shown by Dr. Katz, their actual divergence from approach to a common point at unit value of the equilibrium constant might be indistinguishable, both experimentally and graphically.

Frequently, the amount of heptane and heavier hydrocarbons remaining in a column at the conclusion of a gas analysis is too small for weighing and for molecular weight determination and too large and heavy for satisfactory evaluation by transfer into receivers under low pressure. As a third question: Was a procedure devised for measuring the heptane plus material in these circumstances?

The use of equilibrium constants for estimating dew-point pressures is not always satisfactory because heavy components control results of the computations, and these components are the least accurately determined by analysis. As a fourth question: Do you recommend that the equilibrium constants reported in this paper be used for computing dew-point pressures and, if so, for what range of composition and pressure?

C. E. Webber (author's reply).—The possibility of the curves ever reaching an equilibrium value of unity is remote because of the varying ratios of gas to oil in the experiments. The mixtures were not of identical compositions and were varied under different conditions of temperature and pressure, the aim being to try to simulate conditions that might exist in an absorber. No physical tests were performed above 5000 lb. per sq. inch.

In answer to the third question, the heptane plus material was separated from the gas stream in a small graduated glass trap, where it was measured. In calculating dew-point pressures of complex mixtures, the heptane plus equilibrium value is controlling. If data for heptane plus are available, experience has shown that these data fit in very well at pressures below 2000 lb. Above that pressure, the composition of the mixture has too great an effect upon the equilibrium data and any dew-point calculations would be only approximate.

Fineness and Water-cement Ratio in Relation to Volume and Permeability of Cement

By J. R. Coleman* and G. L. Corrigan,† Student Associate A.I.M.E.

(Tulsa Meeting, October 1940)

Four factors that largely determine the end product obtained when cement and water are mixed are the chemical composition of the cement, the fineness to which the cement is ground, the amount of mixing water used, and the procedure used in mixing the slurry. In order to study the effect of two of these factors, the other two, the chemical composition and method of mixing, are kept constant, leaving as variables fineness and water-cement ratio.

Through years of experimentation and usage it has been well established that the reduction of cement clinker to a very fine state by grinding improves its cementing value, principally because the reaction between cement and water takes place only at the surface of the cement particle, further action being hindered by the accumulation of reaction products that tend to coat the unreacted material. Therefore, the more finely ground a cement, and the greater the surface exposed in proportion to its mass, the more rapid is the hydration rate. Similarly, the greater the surface exposed, the greater the proportion of the cement that reacts, and the lower the amount of residue that is unreacted and so remains inert and unable to make any contribution to cementing properties.[1]

Although it is more expensive to manufacture a finely ground cement than a coarser cement, the advantages of fine grinding of construction cements were so marked that the fineness of cement has increased considerably in past years. When the manufacture of special oil-well cements was begun, it was necessary to consider properties of cement that previously were considered of minor importance, foremost of these being pumpability. Since, with the water-cement ratio constant, a finely ground cement will produce a neat slurry of higher consistency and shorter time of pumpability than will a coarser cement, there is a tendency to grind oil-well cements to a lower degree of fineness. Therefore, in order to produce oil-well cements that will make a slurry having a long time of pumpability, cements are manufactured that because of their coarseness generally are poorer cementing materials than some of the more finely ground construction cements. On the other hand, often it is necessary to pump oil-well cements for long periods of time to place them properly behind a string of casing in a deep well, and since high strength is not of foremost importance for such cement, there is room for considerable controversy concerning the proper fineness range.

The work covered by this paper was done by the authors in pursuance of graduate studies in the Department of Petroleum Engineering at The University of Texas. The present paper is a condensation of a more detailed paper from which, for brevity, information such as the procedure for determining permeability and some of the discussion and procedure relevant to slurry volumes and fineness of cement have been deleted. It was felt that this information would not be of interest to most readers and should be outside the scope of this paper. Manuscript received at the office of the Institute Aug. 16, 1940. Issued as T.P. 1266 in Petroleum Technology, January 1941.

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† Graduate Assistant, Petroleum Engineering Department, University of Texas, Austin, Texas.

[1] References are at the end of the paper.

In addition to pumpability and development of strength, two other properties are essential to a cement suitable for use in oil wells. A good oil-well cement when mixed with water should be capable of hardening into an impermeable and durable mass. It has been well established that when considering any one cement, the denser and less permeable the mass of set cement or concrete produced, the greater will be the durability or resistance to attack.[1] Therefore, since durability is closely related to impermeability, and because it is necessary for cement to harden into a mass having low permeability in order to shut off water in an oil well, impermeability is a doubly important property to be developed by an oil-well cement. It is with this property of cement that this report is chiefly concerned.

Another factor that should be considered is the volume of set cement obtained when cements are mixed at various water-cement ratios. This is important for two reasons: (1) the impermeability is directly related to the ratio of set volume to slurry volume obtained when cement hardens—that is, when a well is cemented with a slurry mixed at excessive water-cement ratios, water that does not adhere to or react with the cement particles tends to move upward in the cement column, possibly forming water channels and water pockets therein behind the pipe, which would, of course, give regions of very high permeability at the points where channels or pockets should occur; (2) frequently an economic advantage can be gained by proper control of the water-cement ratio. Usually there is a range of water-cement ratios at which any particular cement can be mixed and still produce set cement that would not contain water pockets or show evidence of water movement. This range of water-cement ratios is directly dependent upon the fineness to which the cement is ground; that is, a finely ground cement can be mixed at higher water-cement ratios than a coarsely ground cement, without water channeling or the occurrence of water pockets. For these reasons, it is highly desirable to consider in the same study the effect of the various variables on both the permeability developed and the volume of set cement obtained when neat cement slurries harden.

General Procedure and Results

In order to determine what effect fineness has on the permeability and volume of set cement, it was necessary to have available a cement ground to several different degrees of fineness but not varying in chemical composition. One of the major cement manufacturers ground a sample of regular slow-setting "oil-well" cement clinker to four different specific surfaces, ranging from 1206 to 1890 sq. cm. per gram. This range includes within its limits the fineness of practically every oil-well cement now on the market. Some construction cements are used in cementing oil wells and generally they are more finely ground.

The fineness of cement used in these experiments is in all cases expressed in terms of surface area in square centimeters per gram (specific surface) as determined by the Wagner turbidimeter. Details concerning this instrument and its use have been published.[4]

Composition

The chemical analysis and compound composition of this cement are given in Table 1, and for comparison, the averages of the Bogue constituents of four Mid-Continent oil-well cements listed with those of the cement used in these tests.[2] This comparison shows that the compound composition of the cement used in these experiments differed from the average composition of the four Mid-Continent cements in that it contained less C_3S and C_3A and more C_2S and C_4AF; that is, the cement used in these tests contains lower percentages of the compounds that give early strength and higher percentages of the compounds that set and harden more slowly. It might be

TABLE 1.—*Chemical Analysis and Compound Composition*

Constituents	Chemical Analysis, Per Cent
Silicon dioxide (SiO_2)	21.04
Ferric oxide (Fe_2O_3)	7.52
Aluminum trioxide (Al_2O_3)	5.58
Calcium oxide (CaO)	59.35
Magnesium oxide (MgO)	
Sulphur trioxide (SO_3)	1.88
Loss	3.39

Bogue Constituents	Cement Tested, Per Cent	Average Mid-Continent, Per Cent
Tricalcium silicate (C_3S)	28.1	43.9
Dicalcium silicate (C_2S)	39.2	29.5
Tricalcium aluminate (C_3A)	2.1	4.8
Tetracalcium aluminoferrite (C_4AF)	22.9	17.0
Calcium sulphate ($CaSO_4$)	3.2	3.1

noted here that the variation between the compound composition of the cement and the average as shown above is not unusual. It is not necessary for the composition of oil-well cements to conform to any definite set of specifications, therefore a number of cements that differ over a rather wide range are called oil-well cements.

Volume and Weight of Slurry

In this work it was desired to know rather exactly how much slurry could be mixed from a given weight of the cement at different water-cement ratios. Therefore, the slurry volume obtainable at water-cement ratios ranging from 35 to 70 per cent by weight* was carefully measured. For convenience of use, the volumes (Fig. 1) were converted from laboratory units to cubic feet per sack. Throughout this work, as a check on the accuracy attained in mixing the slurry at a desired water-cement ratio, the slurry was weighed for every test (Fig. 1). From the graph in Fig. 1, slurry volumes can be read for any particular water-cement ratio, either percentage by weight or gallons per sack, by using the volume curve and the left ordinate. Similarly, slurry weights may be read using the weight curve and the right ordinate.

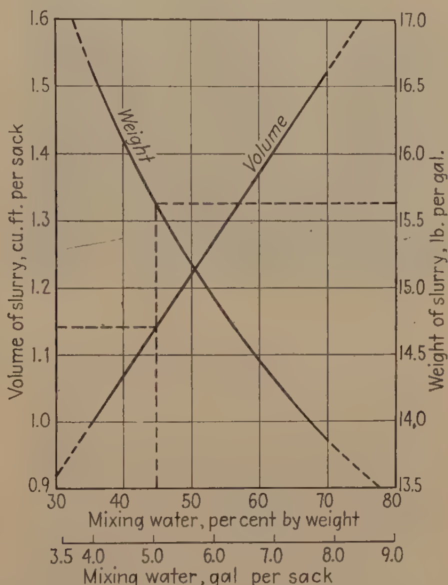

FIG. 1.—VOLUME AND WEIGHT OF CEMENT SLURRY.

Volume of Set Cement

The volume of set cement obtainable was determined for the four degrees of fineness of the cement, each being mixed at four different water-cement ratios. With the exception of special molds, all the equipment used was standard laboratory equipment and requires no description. The parts of one of the molds used and a cement specimen are shown in Fig. 2. The molds were made from standard concrete cylinder molds 6 in. i.d. by 12 in. high, and inside each was centered a steel tubing 12 in. long and 3½ in. in outside diameter, cemented in a neat cement bottom. The mold was formed by the annular space between the 3½-in. o.d. tubing and the 6-in. split steel cylinder. The molds were assembled so that they would hold water without any measur-

* Percentage by weight is used here to mean: (Weight of water/Weight of cement) × 100. All water-cement ratios used in these tests were percentage by weight as here defined.

able loss. The procedure followed in making the tests was:

1. The molds were greased and assembled.

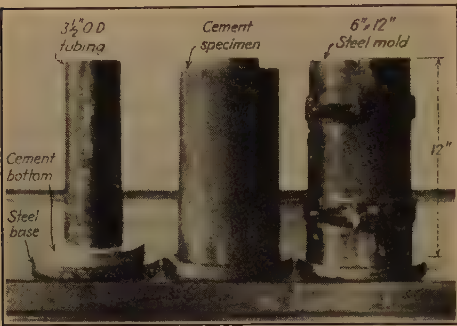

FIG. 2.—CEMENT MOLD.

2. Using a 2-liter graduate, the volume of each mold was measured by filling it with water.

3. The molds were allowed to stand full of water for 15 min. as a test for leakage. Any mold that showed leakage was reassembled and retested.

4. An accurately weighed amount of cement was mixed with the measured amount of water necessary to give the desired water-cement ratio. After the cement was thoroughly wet with the water, the slurry was mixed for 10 min., using an electric stirring device.

5. The weight of the slurry was obtained with a baroid mud balance.

6. The annular space of the mold was filled to the top with slurry. To prevent any error because of different settling rates of the slurries during the time elapsed after stirring and before pouring, the amounts of ingredients for the slurry were calculated, so that only a very small excess was left after each mold was filled; that is, virtually all the cement and water used to make a batch of slurry was poured into one mold.

7. After the cement had hardened for 24 hr., the space between the top of the set cement and the top of the mold was measured by filling with water, using a graduated cylinder.

8. The volume of set cement was obtained by subtracting this volume from the total volume of the annular space.

9. The split cylinders were then removed

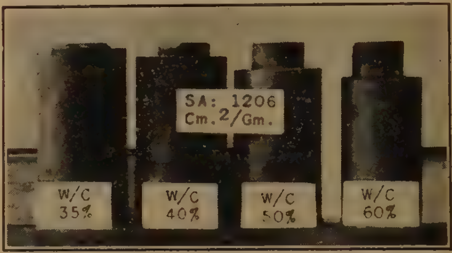

Fig. 3, surface area 1206 sq. cm. per gram.

Fig. 4, surface area 1890 sq. cm. per gram.

FIGS. 3 AND 4.—EFFECT OF WATER-CEMENT RATIO ON VOLUME OF SET CEMENT.

from the specimens of set cement, which were allowed to harden further for use in the permeability tests. A specimen of set cement from which the cylinder has been removed is shown in the center of Fig. 2.

The results of these set-volume tests (Table 2) bring out some rather significant points. It was found that, all other conditions being equal, the ratio of set volume to slurry volume increased as the water-cement ratio was decreased, until for any one fineness of cement a definite water-cement ratio was reached at which the ratio of set volume to slurry volume approached 100 per cent. This point is illustrated by Fig. 3. Using the cement ground to a fineness of 1206 sq. cm. per gram, it was found that the slurry mixed at a water-cement ratio of 60 per cent settled so much before setting that a ratio of set volume to slurry volume of only 77.65 per cent was obtained. On the other hand, the slurry mixed at a

water-cement ratio of 35 per cent set with a ratio of set volume to slurry volume of 96.85 per cent. It should be noted here that even when mixed at a water-cement ratio as low as 35 per cent (3.9 gal. per sack), this cement (surface area, 1206 sq. cm. per gram) settled and set with a ratio of set volume to slurry volume considerably below 100 per cent. This same fact is illustrated again in Fig. 4, but in this case, cement ground to a fineness of 1890 sq. cm. per gram was used. Here a ratio of set volume to slurry volume of 95.25 per cent was obtained even at a water-cement ratio of 70 per cent, and at water-cement ratios of 50 and 40 per cent, cement of this fineness set with ratios of set volume to slurry volume of 99.26 per cent and 100 per cent, respectively.

TABLE 2.—*Volume of Set Cement*

Water-Cement Ratio, Per Cent by Weight	Slurry Volume, Cu. Ft. per Sack[a]	Ratio of Set Volume to Slurry Volume	Volume of Set Cement, Cu. Ft. per Sack
Specific Surface = 1890 Sq. Cm. per Gram			
40	1.069	100.00	1.069
50	1.220	99.26	1.211
60	1.370	97.66	1.338
70	1.521	95.25	1.449
Specific Surface = 1630 Sq. Cm. per Gram			
40	1.069	99.26	1.061
50	1.220	94.88	1.158
60	1.370	88.50	1.212
70	1.521	82.94	1.262
Specific Surface = 1403 Sq. Cm. per Gram			
35	0.994	99.12	0.985
40	1.069	98.67	1.055
50	1.220	91.34	1.114
60	1.370	83.99	1.151
Specific Surface = 1206 Sq. Cm. per Gram			
35	0.994	96.85	0.963
40	1.069	91.61	0.979
50	1.220	83.80	1.022
60	1.370	77.65	1.064

[a] The slurry volumes tabulated were carefully measured in the laboratory and calculated to cubic feet per sack.

The second fact brought out by these tests is that for each fineness of cement there is a definite maximum amount of mixing water that can be used without leaving "excess water."* This amount increases as the fineness of the cement

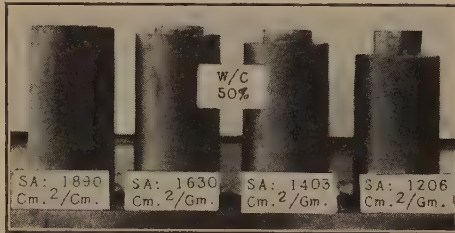

FIG. 5.—EFFECT OF FINENESS OF CEMENT ON SET VOLUME.
Water-cement ratio, 50 per cent.

increases and ranges from 30 per cent for the 1206 S.A. cement to 45 per cent for the 1890 S.A. cement. The gradual increase in the ratio of set volume to slurry volume obtained as the fineness of the cement increased is shown by Fig. 5. These specimens of set cement were obtained when each of the four grinds of cement were mixed at a water-cement ratio of 50 per cent. The ratios of set volume to slurry volume varied from 83.80 per cent for the 1206 S.A. cement to 99.26 per cent for the 1890 S.A. cement, indicating that "excess water" amounted to 16.20 and 0.74 per cent, respectively.

In Fig. 6, the results of all volume tests are shown graphically. The volume of slurry and set cement obtainable per sack of cement for each fineness of cement are plotted against percentage of mixing water and slurry weight. It may be noted that each of the four curves for set cement intersects the slurry line. At these intersection points the set-cement volumes and slurry volumes are equal, and the ratio of set volume to slurry volume would necessarily be 100 per cent; that is, if each of these four grinds of cement should be mixed at the

* "Excess water" is arbitrarily defined as any water used over the maximum amount that can be mixed with a given amount of cement and still produce a slurry with which a ratio of set volume to slurry volume of 100 per cent can be attained.

water-cement ratio that corresponds to the intersection of its respective set-cement curve with the slurry line, the cement would be mixed with the maximum amount

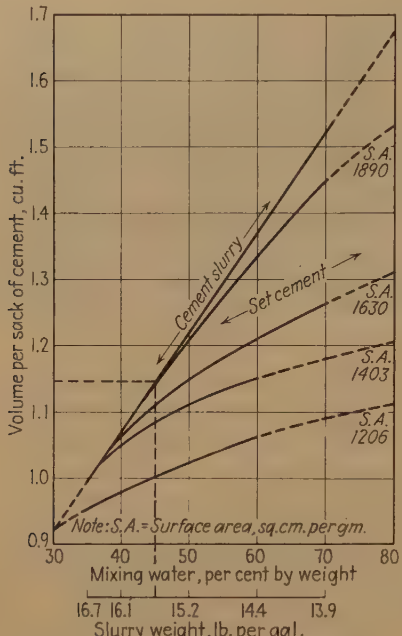

FIG. 6.—VOLUME OF SET CEMENT.

of water that could be used without "excess water." If the cements should be mixed at water-cement ratios exceeding those represented by the intersection points, "excess water" would be used. If the water-cement ratio were in the excess-water range, the attendant dangers of water channels and water pockets in the cement column behind the pipe would be incurred; if the cement were mixed at a water-cement ratio less than those represented by the intersection points, cement would be used in excess of the least amount necessary to give a definite quantity of set cement containing no water channels or large voids. Conditions might make it desirable to cement a well at a water-cement ratio lower than the "optimum"* value, but when a good cement job is essential a water-cement ratio much higher than the optimum value should never be used. The only reason for using a water-cement ratio higher than the optimum would be to use fewer sacks of cement and still obtain a definite fill-up behind the pipe. Such a practice would probably prove to be false economy.

Although all of the excess water in these tests accumulated at the top of the molds, it has been shown by other investigations that this did not occur when molds as high as 6 to 12 ft. were used.[3] Those investigations[3] showed that the volume of the same cement slurry contracted less in setting in a tall form than in a short form. The limitations of equipment prevented the construction of forms taller than 12 ft., but the relationship between the volume of set cement and original slurry volume in 1-ft., 3-ft., 6-ft. and 12-ft. forms was so consistent that the action of the setting cement in a long thin column was predicted with confidence. It was shown that the set-cement volume approached the original slurry volume with an increase in column height in all cases, hence the conclusion was reached that in a long column of cement, such as that used in cementing a string of casing, the original slurry volume would determine the height to which the cement should set behind the casing. It was further concluded that there would be no large quantity of water above the top of the set cement and that most of the excess water would be trapped in pockets or channels at various points in the column of set cement.

In view of the above information, it should be readily understood that the set-cement curves plotted on Fig. 6 are applicable for selecting a suitable water-cement ratio at which to mix a cement ground to a particular fineness, and that they are not

* "Optimum" water-cement ratio is here arbitrarily defined as the maximum water-cement ratio at which a given cement can be mixed and still produce a slurry that will set with a ratio of set volume to slurry volume of 100 per cent.

applicable in determining the amount of fill-up that should be expected. The amount of slurry mixed determines the volume of cement available to fill up the annular space behind the pipe.

Permeability of Cement

Permeability measurements were made for each of the 16 specimens of cement poured for the determinations of set volume. Since in oil-well cementing the cement is usually allowed to harden 72 hr. before it is tested for a water or gas shutoff, it seemed desirable to make the permeability measurements after the cement specimens had hardened for 72 hr. Therefore, in addition to the 24-hr. curing allowed before the volume of set cement was measured, for the permeability measurements the specimens were allowed to harden an additional 48 hr. The cement was allowed to remain in the molds at room temperature (85° to 95°F.) during the first 24 hr.; then the molds were removed and the specimens were cured in water at 100°F. for the remaining two days. Six permeability cores were cut from each of the specimens. In order to determine the limits of the permeability variation, three of these cores were cut from the top and three from the bottom of each specimen. The top and bottom cores were all horizontal, cut along a circumference at a distance of one inch from the tops and bottoms, respectively, of the specimens. As soon as the cores were cut they were dried in an oven at 212°F. for approximately 6 hr. The cores were then allowed to cool in a desiccator before the permeability measurements were made.

The apparatus used in making the permeability measurements was regular permeability equipment ordinarily used in determining the permeability of sand or limestone cores with air. Details concerning the procedure used for determining permeabilities have been given by Fancher, Lewis and Barnes.[5]

The results of these measurements are tabulated in Table 3. The permeability values obtained for the cores from the top and bottom of each specimen were averaged

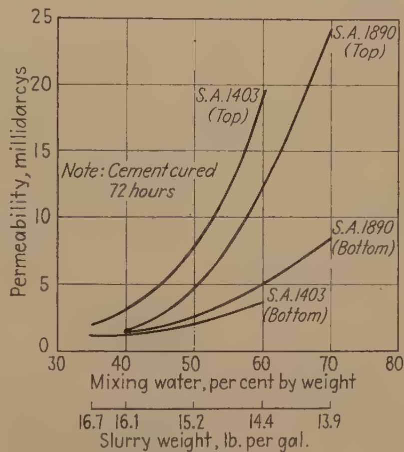

FIG. 7.—PERMEABILITY VARIATION DUE TO SETTLING.

separately. These averages show that there is little difference between the permeabilities of the tops and bottoms of the specimens mixed at low water-cement ratios, but that the specimens mixed at high water-cement ratios differed widely in permeability between the bottom and top of the specimens. This difference was due to settling of the cement particles before the cement took an initial set; that is, as the cement was setting the cement particles settled and the "excess water" moved upward, collecting at the tops of the molds. The permeability variation for two of the grinds of cement is illustrated by Fig. 7. Two points should be noted from this curve: (1) the difference in permeability between the top and bottom of the specimen due to settling increased markedly as the water-cement ratio increased; (2) this difference in permeability was greater for the coarse cement (S.A. 1403) than for the finer cement (S.A. 1890), showing the greater tendency for the particles in the more coarsely ground cement to settle.

For the purpose of comparing the permeabilities developed by cements of different degrees of fineness, the average permeability of each specimen of set cement was calculated, and the values are plotted on Fig. 8. From this figure, it can be readily seen that the permeabilities of all of the grinds of cement increased rapidly as the water-cement ratio was increased. These permeabilities increased from 1.5 to 16 millidarcys as the water-cement ratio was increased from 35 to 70 per cent. Although the permeabilities developed by the cements when mixed at water-cement ratios as high as 70 per cent were measured, it should be remarked that the permeabilities of none of these cements would have appreciable actual significance at a water-cement ratio above the optimum value, because at ratios above the optimum, excess water collected on top of the molds while the cement was setting. If any of this cement, when mixed at a water-cement ratio exceeding the optimum, should be used in cementing an oil well, the excess water present would tend to collect as water pockets in the column of cement and form regions of very high permeability behind the pipe. On Fig. 8 is plotted an optimum water-cement ratio line, which was obtained by taking the intersection of each set-cement curve with the slurry line from Fig. 6 and replotting these values on Fig. 8. It should be noted that when mixed at or below their respective optimum water-cement ratios, all of these cements developed permeabilities that were very low in comparison to the permeabilities developed at the higher water-cement ratios.

TABLE 3.—*Permeability of Cement*

W/C, Per Cent by Weight	Permeabilities of Specimens, Millidarcys							
	S.A. 1890		S.A. 1630		S.A. 1403		S.A. 1206	
	Tops	Bottoms	Tops	Bottoms	Tops	Bottoms	Tops	Bottoms
35					2.20	1.25	2.29	1.55
35					1.93	1.13	2.22	1.29
35					2.22	0.86	2.53	1.51
Average					2.12	1.08	2.35	1.45
40	1.39	1.40	1.89	1.76	3.68	2.29	3.79	1.60
40	1.54	1.41	3.23	1.90	3.17	1.80	4.58	1.87
40	1.38	1.70	2.03	1.48	4.19	2.16	4.44	1.67
Average	1.44	1.50	2.38	1.71	3.68	2.08	4.27	1.71
50	4.80		4.51	4.56	6.12	1.71	7.37	1.38
50	4.04	2.14	4.29	1.76	6.05	1.74	8.03	1.48
50	4.28	2.66	4.11	1.54	8.69	1.99	9.90	1.73
Average	4.37	2.40	4.30	2.61	6.95	1.81	8.43	1.53
60	14.36	5.71	17.30	5.51	21.71	3.61	12.91	5.07
60	14.61	6.37	17.54	3.75	19.34	3.79	11.78	
60	11.39		18.67	4.11	17.15	3.38	14.81	6.21
Average	13.45	6.04	17.84	4.46	19.40	3.59	13.17	5.64
70	23.65		25.66	5.07				
70	22.72	9.98	25.73	3.87				
70	26.30	5.86		4.32				
Average	24.22	7.92	25.69	4.42				

In order to determine just what effect the fineness of grind had on the permeability developed by the set cement, permeability was plotted against specific surface for water-cement ratios of 35, 40 and 50 per cent, as shown in Fig. 9. Also, on the same graph was plotted the optimum water-cement ratio line. Although all of these permeabilities were rather low, a decrease in permeability with an increase in specific surface was found.

These tests were made for two specific purposes: (1) to determine what effect the fineness to which a cement is ground and the amount of mixing water used in the

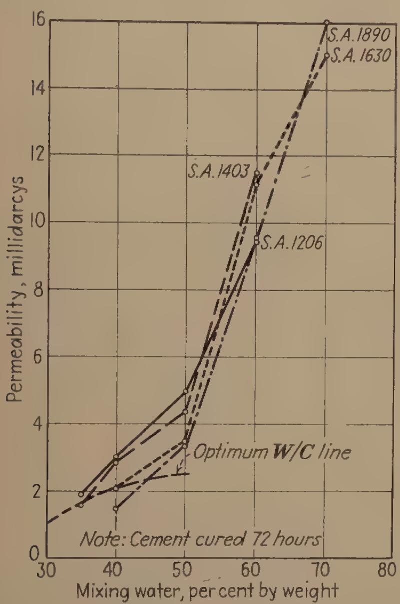

FIG. 8.—PERMEABILITY VERSUS WATER-CEMENT RATIO.

slurry have on the volume of set cement obtained per sack of cement; and (2) to determine the effect of these same two variables on the permeability of the cement after it hardens. It is believed that these tests accomplish these purposes, but, because of such factors as pressure, high curing temperatures, change in volume of cement on drying, and change in properties of cement with age, these same values of permeability would not necessarily be expected in an oil well. When compared to the permeabilities found in oil sands the permeabilities found in these tests would be called low; in fact, they are of about the same magnitude as the permeabilities found in some Bradford sand that is being waterflooded.[5] However, for a material designed to shut off water, this slow-setting cement, for all degrees of fineness tested, showed very high permeabilities under these test conditions.

Since all of the measurements described above were made after the cement had

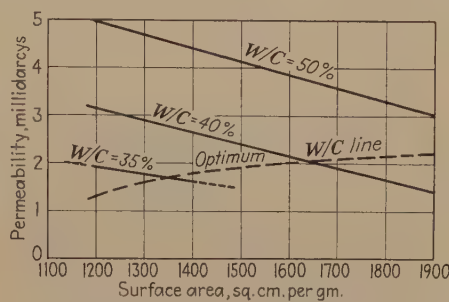

FIG. 9.—PERMEABILITY VERSUS SURFACE AREA OF CEMENT.
Cement cured 72 hours.

cured for 72 hr. at low temperatures, further tests were made to see how impermeable the cement would become when cured at a higher temperature. Also, permeabilities were measured after 14 days of curing as well as at 3 days of curing. For a comparison, permeabilities were measured of specimens of Portland cement cured under the same conditions as the slow-setting oil-well cement. A fineness of the slow-setting cement very close to the fineness of the Portland cement was chosen, thus leaving chemical composition as the main variable. To see how fineness would affect the permeability of cement cured at a high temperature, a coarse grind of the oil-well cement was tested also. All of these

TABLE 4.—*Measurements at High Temperatures*

Curing Time, Days	Core Number	Permeability, Millidarcys		
		Portland Cement, S.A. 1843	Oil-well Cement	
			S.A. 1890	S.A. 1403
3	1	0.069	0.282	0.915
3	2	0.058	0.314	0.934
3	Average	0.0635	0.298	0.925
14	1	0.050	0.038	0.139
14	2	0.049	0.037	0.168
14	Average	0.0495	0.0375	0.154

cements were mixed at a water-cement ratio of 40 per cent and were cured at 150°F. The permeabilities of two cores cut from different specimens were measured for each of the cements. The results of the measurements are given in Table. 4. The following points seem important:

1. Although each core was cut from a different specimen, the permeabilities of different cores for any one cement at either 3 or 14 days did not differ greatly. These tests suggest that permeability, or impermeability, is possibly as consistent a property of cement as is strength, setting time and other properties.

2. As would be expected, the permeabilities of all the cements were considerably lower at 14 days than at 3 days.

3. The permeability of the Portland cement was much lower at 3 days than was that of either fineness of the oil-well cement, largely because the Portland cement, owing to its chemical composition, hardened at a much faster rate than did the slow-setting oil-well cement.

4. After 14 days of curing, the permeability of the oil-well cement, S.A. 1890, and that of the Portland cement, S.A. 1843, did not differ greatly, the permeability of the Portland cement being slightly higher.

5. Of the two grinds of oil-well cement, the coarse grind, S.A. 1403, was much more permeable than the fine grind, S.A. 1890, after both 3 and 14 days.

To show how much high curing temperature speeds up the development of impermeability, the permeabilities of specimens of Portland and oil-well cement cured at 90° and 150°F. were measured (Table 5).

Table 5.—*Effect of High Curing Temperature*

Age of Specimens, 3 Days

Temperature, Deg. F.	Portland, S.A. 1843, Millidarcys	Oil-well, S.A. 1890, Millidarcys
90	0.179	1.943
150	0.064	0.298

It should be noted that for both cements the permeabilities of the specimens cured at 150°F. were very much lower than those cured at 90°F. This, of course, is consistent with the increase in hardening rate that occurs with an increase in curing temperature.

Summary of Results

From the determinations of the volume of set cement the following results and conclusions seem pertinent:

1. With all other conditions equal, it was found that the ratio of set volume to slurry volume increased as the water-cement ratio was decreased, until for any one fineness of cement a definite water-cement ratio was reached at which the ratio of set volume to slurry volume approached 100 per cent.

2. For each fineness of cement there is a definite maximum ("optimum") amount of mixing water that can be used without using any "excess water." This amount of water was found to increase as the fineness of cement increased, and ranged from 30 per cent for the 1206 S.A. cement to 45 per cent for the 1890 S.A. cement.

From the permeability measurements made on the specimens of set cement, the following results seem important:

1. There was little difference in the permeabilities of the tops and bottoms of the cement specimens mixed at low water-cement ratios (water-cement ratios equal to or less than the "optimum" water-cement ratio).

2. Specimens of cement mixed at high water-cement ratios showed much higher permeabilities at the tops of the specimens than at the bottoms.

3. The differences in the permeabilities of the tops and bottoms of the specimens decreased as the fineness of the cement increased and probably were largely caused by settling of the cement particles as the cement was setting.

4. The permeabilities of all the cements increased with the water-cement ratio.

5. Other factors being constant, at

water-cement ratios between 35 and 50 per cent there was a decrease in permeability with an increase in fineness.

6. The permeability of all cements tested decreased with an increase in age or curing temperature.

7. The rates at which the cements developed impermeability apparently were consistent with the rates at which ordinarily they harden.

Acknowledgment

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Some Theoretical Considerations on the Problem of Well Shooting

By H. H. Evinger* and M. Muskat*

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Although the shooting of oil wells for the purpose of increasing production has been practiced since 1866, present-day shooting technique has been arrived at almost wholly by a process of trial and error. The difficulties attending either a theoretical analysis of the problem or an experimental attack become apparent when one actually embarks on a theoretical investigation or attempts to formulate an intelligent experimental program. The literature on the subject consists mainly of descriptions of current practice, scattered eye-witness accounts of events following the shooting of a well, and vague speculations on the mechanical processes involved.

In contrast to quarry blasting, the results of oil-well shooting cannot be determined by means of visual inspection, and it is perhaps for this reason that only one attempt at what approaches a direct experimental attack has been reported in the literature.[1] In these experiments, charges of liquid nitroglycerin were exploded in holes drilled in a sandstone outcrop. In order to observe the character and extent of the resulting fractures, the rock was blasted away so as to expose the original shot holes. After all this had been done it was found impossible to distinguish the fracturing due to the original shots from that due to the subsequent blasting. The enlargement of the holes due to the pulverizing action of the shots was measured and an attempt was made to determine the effectiveness of sand tamping. Only five shots were made and few definite conclusions could be drawn.

Some small-scale experiments to determine the effect of tamping were performed by Snelling and Hall.[2] Small charges (20 grams) of dynamite were detonated at the bottom of a cylindrical hole in a lead block and the resulting enlargement of the hole was taken as a measure of the effectiveness of the explosion. It was found that when the shot was tamped with a sufficient amount of sand or clay, the volume enlargement was approximately double that found when no stemming had been used.

The properties of the explosives have been the subject of much study by the manufacturers, the U. S. Bureau of Mines, and various other agencies. For example, velocities of detonation for many commercial explosives are to be found in the Blasters' Handbook, issued by the Du Pont company. Many other properties are given in a treatise on the subject by Naoum.[3] The shock wave that accompanies the detonation of high explosives has been studied photographically by Payman[4] and others. The hydrodynamical theory of the shock wave has received much attention, and an extended theoretical treatment is given by Bateman.[5]

Two aspects of the well-shooting problem will be considered in this paper; namely, the fracturing of subsurface strata, and possible damage to casing. With respect to the former of these, several calculations have been made giving the stresses in the rocks surrounding the shot. In order to arrive at numerical results at all, however, it is necessary to introduce a great many simplifying

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[1] References are at the end of the paper.

assumptions, and for this reason none of these results can be considered as quantitatively accurate. On the other hand, unless these assumptions are made, about all that can be done is to discuss qualitatively the types of stress that probably occur and to speculate on the mechanism of failure in the rocks. Of course, no claim is made that the following discussion gives a solution in any sense of the practical problems of well shooting. Rather, it is presented only as an outline of the physical elements involved, and for the purpose of stimulating interest and further work by others who are also seeking improvements in the art of well shooting.

The Explosion Process

Because the desired effects of a shot are the direct consequence of the application of pressures on the walls of the hole, it is necessary to consider the probable history of these pressures following the detonation of the shot. If the detonating agent is placed at the top of the explosive column, the wave of detonation will travel downward through the column with a velocity that may attain values in excess of 20,000 ft. per sec. Behind the detonation wave are the expanding gaseous products of the explosion. As shown by the photographic studies made by Payman[4] of unconfined explosions, the gaseous products of the explosion are preceded by a shock wave whose velocity may be several times that of sound in air under normal conditions. However, on account of the extremely short duration of the shock wave, and the relatively small amount of energy it carries, it seems unlikely that the shock wave is an important agent in the creation of fractures in the rocks surrounding the shot. We shall consider therefore only the pressures exerted on the walls of the hole by the gaseous products themselves. These pressures are a source of much uncertainty. If the gaseous products of liquid nitroglycerin are confined to the volume originally occupied by the liquid, and if no heat losses are permitted, calculation[3] gives a resulting pressure of about 150,000 lb. per sq. in. This figure is based upon the assumption that the products of the explosion behave as perfect gases, but since the temperatures and pressures of the explosion are much too high for the perfect gas laws to give good approximations, the calculation is probably valid only with regard to order of magnitude. The general belief of workers in this field seems to be that if a charge of nitroglycerin could be perfectly confined, the explosion pressure might reach 1,000,000 lb. per sq. in. However, since it is practically impossible to confine gases under such pressures, the pressure applied to the walls of the hole during the explosion probably does not attain such a high value.

In addition to the uncertainty as to the maximum value of the pressure resulting from the explosion, an even greater one is encountered in attempting to estimate the time rate at which this pressure is applied to the walls of the hole. In some of the calculations that follow it is shown that this time rate is probably as important as the pressure itself in determining the stresses in the rocks.

Stresses Resulting from the Explosion

In general, mechanical failure of rocks can be caused by the application of any one of the three types of stress; that is, compression, tension, and shear. Compressive stresses are probably less important in well shooting than either tension or shear, and their principal manifestation is the pulverizing that occurs in the rock immediately surrounding the shot. Cracking and splitting of the rock can be produced either by tension or by shear. In the case of tension, failure is the result of the rock simply being pulled apart, whereas the effect of a shearing stress is to produce differential displacements along parallel planes.

Owing to the finite velocity of detonation, it is clear that the application of pressure to the sides of the hole will occur first at the top of the explosive column and then proceed downward. This process is in itself rather complicated because there are three distinct velocities involved. First, there is the velocity of detonation; that is, the velocity at which the beginning of decomposition is propagated. Then there are the wave velocities characteristic of the fluid within the hole and of the rock surrounding the hole. Since the first of these is probably considerably greater than the others, the initial application of pressure at a given point in the hole will be due only to the decomposition of explosive in the immediate neighborhood of the point in question. Indeed, if the rate of decomposition of the explosive is sufficiently great, maximum pressure will be attained before a pressure wave initiated farther up the hole could arrive. In this case, owing to the absence of pressure differentials over any considerable distance in the interval between the top of the explosive column and the detonation front, the main disturbance will be propagated downward with the velocity of detonation rather than with the wave velocity of the fluid within the hole. At points on the walls of the hole above or below the charge, the front of the disturbance will probably arrive through the surrounding rocks rather than through the material within the hole, because of the relatively slow velocities of propagation through the fluids in the well bore.

The problem then is to calculate the stresses in the rocks surrounding the shot hole due to pressures within the hole, which depend not only upon time but also upon the distance from the top of the explosive column. Unfortunately, it appears that there would be little chance of obtaining an exact solution to this problem even if the manner in which the pressure in the hole is built up were known and if, in addition, an ideal elastic medium were assumed. However, various simplifications of this fundamental problem will be discussed in an effort to throw some light on the processes involved. In addition to these simplifications, we shall also make the same basic physical assumptions that underlie the whole of the classical theory of stress analysis.

For example, whereas rocks actually are neither homogeneous nor isotropic, we shall assume them to be so in our theoretical discussion. Moreover, although their obedience to Hooke's law is not very close even before failure occurs, and we shall be interested mainly in cases where failure does occur, the validity of Hooke's law will be assumed nevertheless in the analytical developments.

In the published literature on the mechanical properties of rocks (for instance, Johnson's Materials of Construction[6]), most of the data are for building stones, which probably have greater strength than the average oil-bearing formations. For these, the tables indicate, as would be expected, that rocks have much greater resistance to compression than to shear or tension. Values of 5000 lb., 500 lb. and 200 lb. per sq. in. seem to be typical for the maximum strengths in compression, shear, and tension, respectively, and, for want of better ones, will be used in subsequent calculations. Moreover, for stratified rocks their strength will obviously be least against shearing forces parallel to, and tension perpendicular to, the bedding planes.

In the following paragraphs the results of a number of stress calculations are given. These stresses have been calculated as a function of the distance from the center of the initial disturbance. The distance below which the stress exceeds the maximum strength of the rocks is termed the "radius of fracture."

Effect of a Pressure Pulse in a Spherical Cavity

A case that can be solved theoretically, and which probably would give a close

approximation to certain aspects of the actual shooting process, is that of a pressure pulse acting on the walls of a cylindrical hole of infinite length. However, the work required in making the numerical calculations turns out to be so great that it could hardly be justified in view of other questionable assumptions that would have to be made. Fortunately, however, the corresponding case of a spherical cavity is not very difficult of solution and for distances from the shot hole that are large compared to the length of the explosive column the spherical case should actually give an even better approximation. In particular, this problem provides a rather enlightening comparison between the effects of a pressure pulse and those resulting from the application of purely static pressures. Thus, if p is the static pressure exerted on the inside of a spherical cavity of radius a, the radial compressive stress P and the tangential tension Q are given by the equation:[7]

$$-P = 2Q = a^3p/r^3 \qquad [1]$$

where r is the distance from the point in question to the center of the sphere. Here the radius of fracture varies as the cube root of the applied pressure. In particular, if p is taken as 500,000 lb. per sq. in., 200 lb. per sq. in. as the ultimate strength of the rocks in tension, and 1 ft. as the radius of the cavity, the fracturing radius is found to be about 11 feet.

If, however, we consider the effects of a pressure increasing with time up to a certain maximum value, an entirely different state of affairs is encountered. Whereas in the static case the stresses decrease as the inverse cube of the distance, it is found that if a pressure pulse is applied within the cavity, the maximum stress that obtains at a given point will, for sufficiently large distances from the center, fall off only as the inverse first power of the distance. The expressions for the stresses are rather complicated and are given in section 1 of the Appendix, with the complete analysis of this problem. Here we shall refer only to the results of the numerical calculations. The pressure in the cavity at a time t after the explosion was assumed to be given by the equation:

$$P = P_0(1 - e^{-kt}) \qquad [2]$$

where P_0 is the maximum value attained by the pressure, and k is a constant, which is a measure of the speed at which the pressure is applied.* In fact, according to Eq. 2, the pressure will attain approximately one-half its maximum value when $t = 0.7/k$. The ultimate effect of the rate of pressure build-up constant k upon the fracture radius is:

k............	0	10^3	10^4	2×10^4	∞
R, ft.........	4	5	43	58	75

where the radius of the spherical cavity was taken as 4 in. and P_0 was assumed to be 500,000 lb per sq. in. The fracture radii R are those to which the maximum tension stress will exceed 200 lb. per sq. in. The zero value of k represents the static case already discussed, and $k = \infty$ represents the instantaneous application of pressure. This table clearly shows the importance of the rate at which the pressure is built up.

It is true, of course, that the actual pressure in a shot hole does not increase in any such simple manner as that expressed by Eq. 2. Regardless of what form of pressure increase is assumed, however, the rapidits of increase will be important in determininy the fracturing radius and, since theeg calculations are not intended to be quantitatively accurate, Eq. 2 should be satisfactory for the present purposes. Some other pressure-time relation could have been chosen, but undoubtedly would have also shown the time rate to be of great importance. However, it should be noted that no effect of absorption has been taken into

* This speed is not to be confused with the velocity of detonation, which is a measure only of the rate of vertical travel of the detonation wave through the explosive column.

account in these calculations. With absorption present, it is possible that the high-frequency components of the pulse may be attenuated so rapidly that, at points appreciably distant from the hole, the resulting stresses may be higher if a slower pulse is applied—that is, one with more low-frequency components.

Effect of Tamping

Perhaps the most obvious reason why tamping should increase the effectiveness of a shot is that, owing to the confining action, the pressure in the hole is increased.

A second effect of tamping is the creation of vertical tensions, which tend to cause splitting along horizontal planes. If radial pressures are applied to the walls of a cylindrical hole, with no confinement provided at the ends of the explosive column, it is clear that there will be no vertical tensions that would tend to lift the overburden. However, if sufficient tamping be provided to transmit vertical forces to the walls of the hole, these vertical forces against the tamping column will be transmitted throughout the surrounding rocks as vertical tensions. An exact analytical solution of this problem is not possible, but a modification of the corresponding static problem is treated in section 2 of the Appendix. The case referred to is that of static radial pressures applied to the walls of the upper half of a spherical cavity with zero pressures on the lower half. The resulting stress distribution superposed on that for the simple cylindrical case can be thought of as applying to a tamped shot. This representation, admittedly idealized, presupposes perfect tamping, or that the hole above the explosive has been replaced with the original undisturbed rock. Open hole below the shot is roughly taken care of by assuming zero pressure on the lower half of the cavity. Obviously, any actual tamping will be less effective than has been assumed, so that the magnitude of the vertical tensions found in this manner will constitute upper limits to the rigorous solution. The general expressions for the stresses are rather complicated but, with the exception of the shear, reduce to simple forms on the horizontal plane through the center of the spherical cavity. It is found, for example, that the tension at a distance r from the center of the cavity, acting across this plane, is given by:

$$T = p_0 a^3/4r^3 \qquad [3]$$

where p_0 is the pressure applied to the upper half of the cavity of radius a. This value for the tension is seen to be just one-half that given by Eq. 1 for the case in which the pressure is applied over the entire spherical boundary.

The analysis has not been carried out for the case of a pressure pulse applied over a hemisphere, but we shall assume the tension across the horizontal plane through the center of the cavity to be one-half that given by the analysis on page 226. This assumption seems at least plausible if one considers that the static problem represents a limiting case of the pulse; that is, the case for which $k = 0$. In this manner we shall be able to calculate the tendency for a tamped shot to create horizontal fractures.

In order that fracturing of this type may take place, it is necessary that the tensional stress exceed the vertical compressive stress due to the weight of the overburden by an amount equal to the tensile strength of the rock. Assuming an overburden pressure of 3000 lb. per sq. in., p_0 as 500,000 lb. per sq. in., and a cavity 8 in. in diameter, the following distances, R, are found for different values of k, within which the resulting tension across the horizontal plane would be sufficient to cause failure:

k.........	0	2×10^4	∞
R, ft......	1.1	2.7	3

Since any actual tamping would be much less effective than we have assumed, tension would seem to be relatively unimpor-

tant in the creation of horizontal fractures, especially in deep wells where the overburden pressure is high.* These values of R are much less sensitive to changes in k than were those given on page 219. This arises from the fact that the tensile stress that must be overcome here in order to create a fracture is so much larger, because of the overburden effect, than that needed to create vertical-tension fractures. As shown in Fig. 1, in the Appendix, the curves for different values of k rapidly converge as the stress is increased, thus leading to but a slow variation with k of the radius at which any such high stress will be attained.

Traveling Pressure Pulse in a Cylindrical Hole

Although, as mentioned, the stress distribution due to a pressure pulse traveling down a cylindrical hole has not as yet been calculated, the nature of the resulting stresses may be discussed qualitatively. As in the static case, we should expect a system of compressive stresses acting radially and of tensions acting tangentially. The effect of these tensions if sufficiently large in magnitude would be to cause fractures along radial planes and to enlarge such cracks as may have been already present in these planes. In addition to these, a system of shearing stresses will be present, due to the finite velocity of detonation. The existence of these stresses is made plausible by considering that in the early stages of the detonation the radial stresses and displacements are greatest at points in the neighborhood of the upper part of the explosive column. This variation in radial displacement with depth will give rise to components of shearing stress along horizontal planes. Since the resistance of rocks to shear is least along the bedding plane, these shearing stresses may be quite important in causing fractures.

Another source of horizontal shearing stresses may lie in the lack of uniformity of the rock strata. If, owing to a change in rock type, two adjacent beds have different values of Young's modulus, the one having the lower value will undergo the greater average radial displacement, and failure may occur along the contact. This type of shear will occur even when static pressures are applied in the hole.

An attempt has been made to solve the problem of a pressure pulse in an infinite cylindrical hole for the case in which the applied pressure is a function of time only and not of the depth. Although the problem was not solved completely and no numerical calculations have been carried out, it appears that, for comparatively large distances from the hole, the maximum stresses will decrease as $1/\sqrt{r}$. For the analogous static case the stresses decrease as $1/r^2$.

Comparison of Solid and Liquid Stemming

In the foregoing discussions, two effects of tamping have been mentioned: (1) the creation of vertical forces tending to cause splitting in horizontal planes and (2) the increase in gas pressure resulting simply from the additional confinement provided by the stemming. It is clear that all of these effects will be increased by decreasing the mobility of the stemming.

Two factors tend to prevent the stemming from being pushed up the hole by the explosion. One of these is inertia. However, since the mass density of unconsolidated sand is not appreciably greater than that of water, one should expect fluid stemming to be nearly as satisfactory as sand if the forces of inertia alone are involved. On the other hand, there will be a superiority of sand over fluid stemming because of the greater frictional coupling with the walls of the hole and the accompanying wedging effect in connection with the former. Thus it is a common occurrence for solid material

* In principle the same calculation and conclusion will also be applicable to whatever effect the closure of the hole by the well bottom may have in inducing stresses for creating fractures.

to form a bridge in a hole, whereas that would be impossible in a liquid except in tubes of capillary diameter. The resulting limitation in volume in which the gases may expand will thus increase the maximum pressure developed.

Effect of Overburden on Creation of Vertical Fractures

In the discussion of the development of vertical fractures, no consideration was given to the initial stresses due to the overburden. For rocks of density 2.3, there will be a compressive stress acting vertically of 1 lb. per sq. in. per foot of depth. As previously stated, this compression will tend to prevent the shot from causing horizontal fractures by lifting the overburden. In addition to this vertical stress, it is possible for the overburden to create horizontal compressive stresses. The magnitude of this stress will depend upon the lateral displacement permitted, and, of course, upon local structural conditions. For a medium having a value of 0.25 for Poisson's ratio (an average for such rocks as have been measured), it can be shown that the horizontal compressive stress due to the overburden will be one-third the vertical stress provided that no lateral displacements are allowed. Actually, because of the presence of vertical cracks, the horizontal stress may be considerably less than one-third the vertical stress, and whatever effect it may have will be to decrease the effect of the tangential tensions, resulting from the shot, in causing vertical fractures.

Damage to Casing

With regard to this phase of the problem, the quantitative theoretical attack seems to offer even less promise than it did in discussing the effect of the shot on the surrounding rock. Probably the most that can be done is to formulate a qualitative theory by which the observed facts can be correlated.

The few data available concerning casing failure show that quite frequently failure in the pipe occurs several hundred feet up the hole from the shot. Fluid levels are not always given, but statements in the literature seem to indicate that failure commonly occurs near the fluid level.

Energy can be transmitted from the shot to the pipe through two channels: (1) through the rock surrounding the pipe, and (2) through the fluid within the pipe. Since disturbances in the rock will be attenuated rapidly, it would be difficult to explain, in this manner, casing failures several hundred feet above the shot. Moreover, if damage to casing were effected by forces transmitted through the rock, stemming would not offer any protection to the casing except for the increased resistance to collapse in the part of the casing that is filled by the stemming. On the other hand, most of the energy imparted by the shot to a fluid column will remain concentrated in the fluid and not spread out in the surrounding rock. It is difficult in general to transfer energy from one medium to another when the two media have greatly different elastic properties, and in this case energy would have to be transferred from the fluid to the pipe, and then to the rocks in order to dissipate the disturbance before it reaches the top of the fluid. These considerations make it seem at least plausible that the fluid column may be able to carry energy for comparatively long distances.

Upon detonation of the shot, the fluid at the bottom of the pipe will be compressed and a compression wave will travel upward through the fluid. As this disturbance passes a given point in the pipe, a radial force will be exerted upon the pipe. Also, since at any given time this radial force will vary from point to point along the pipe, shearing stresses will be set up perpendicular to the pipe's axis. Since the pipe will not be subjected to outward radial pressure above the fluid level, the axial variation of the radial pressure, and hence the resulting

shearing stresses, will be greatest in the neighborhood of the fluid level. It is therefore not unreasonable to expect more frequent casing failures at the fluid level, in liquid tamped shots, than elsewhere along the string.

Another possible reason for a higher concentration of the stresses at the fluid level than elsewhere lies in the reflection at the fluid level of the longitudinal compressional wave rising in the liquid column. Such a reflection will lead to a doubling of the amplitudes of the disturbance, and hence will accentuate the displacements and stresses in the flow string opposite the fluid level. However, as the interaction between the flow string and the longitudinal displacements in the fluid column are due only to frictional coupling, it is questionable whether high enough stresses could be transferred in this manner to the casing to cause failure.

A consideration of energy relations also furnishes a reasonable explanation of the observed superiority of solid over liquid stemming as a means of preventing damage to casing. If the hole above the shot is filled with liquid only, the energy will be transmitted through the fluid with little absorption until it is transferred to the pipe at the top of the fluid column. On the other hand, a solid stemming material such as sand is capable of permanently absorbing more energy than a fluid, and hence of preventing this energy from reaching the pipe. Although these theories cannot be supported by calculation, they do explain the effectiveness of solid stemming and also the fact that casing failures frequently occur at the fluid level.

Conclusions and Suggestions for Further Study

Owing to the inherent complexity of the problem, and to the consequent analytical difficulties, it has not been possible to take into account all of the factors involved in the problem of well shooting, and to discuss quantitatively the sequence of events following the detonation of a shot. By the introduction of certain simplifying assumptions, however, numerical values have been obtained, which should give some idea as to the magnitude of the effects to be expected. One can, for example, discuss the manner in which the fracturing radius varies with the quantity of explosive. If it is assumed that the maximum pressure in the hole varies directly with the concentration of explosive, it is found that for static pressures in the cases of cylindrical and spherical cavities, the fracturing radius varies respectively as the square root and cube root of the size of charge. If one takes into account the time rate at which pressure is applied, it is found that for the spherical cavity the fracturing radius varies approximately with the first power of the size of charge.

Another fact brought out by the numerical calculations is that tamping is ineffective in the creation of horizontal fractures by lifting the overburden. It appears, however, that aside from its function of serving as protection to casing, tamping may increase the horizontal shearing stresses and thereby increase the fracturing effect of a shot. Calculations also show that the time rate at which pressures build up is very important, but it is not advisable to go to the extreme in the matter of detonation speeds because of the increasing effects of local shattering that undoubtedly will accompany the higher speeds of detonation, and the effect of high-frequency attenuation mentioned on page 220.

Some of the qualitative ideas offered here suggest subjects for field experimentation. In the shooting of wells, only a few factors are subject to control. The kind and quantity of stemming, the quantity, nature, and distribution of explosive, and the amount of open hole between the top of the shot and the casing seat can be varied. Beyond this, not much can be done. If the primary consideration is to prevent energy from reaching the fluid column in the pipe, the

stemming should be comparatively rigid and capable of transmitting energy away from the fluid column to the walls of the hole. In this respect a fluid would be poorest and a solid cement plug best. If setting a cement plug is not feasible, a variety of solid materials such as sand, gravel, and crushed stone might be used. It seems fairly clear that the frictional coupling with the walls of the hole, and therefore the wedging effect, would be greater if the stemming consisted of sharp angular particles rather than smooth gravels. Probably the best stemming from this point of view would consist of an aggregate of angular particles ranging in size from sand to pieces as large as could be cleaned out with a sand pump. Some investigations could be made in the course of routine well shooting to determine the relative efficiency of different types of stemming and also the minimum amount of stemming that should be used.

An experimental program to determine the effect of the quantity, nature, and distribution of explosive would necessarily be more elaborate than that for the investigation of the effect of stemming. Increase in productivity factor resulting from a shot could be taken as a measure of the effectiveness of the shot, and, owing to the variation in conditions among wells, any definite conclusions could be arrived at only by a statistical study of the results of a fairly large number of cases. Such experiments should, of course, be carried on in a field where conditions vary as little as possible between wells.

With regard to the determination of the amount of explosive required to produce the desired effect, it does not appear that any substantial improvement can be made on the method now in use; that is, simple trial and error. It is possible, of course, to measure the enlargement of the hole resulting from a shot. One method[8] consists in shoveling a solid material, such as crushed stone, into the hole. The hole diameter can then be calculated from the volume of crushed stone required to raise the level of the stone in the hole by a specified amount. A more recent method[9] employs an instrument, which is lowered into the hole and gives direct readings of hole diameter. Such measurements, however, would not give direct information regarding the creation of fractures. The principal objective in shooting a well is the fracturing of rocks out to a considerable distance rather than pulverization in the immediate vicinity of the hole. The relationship between these two effects is not at all obvious, and it is conceivable that doubling the size of a shot might increase the pulverizing effect in a higher ratio than it would the radius of fracture. For this reason, it would seem that the mere enlargement of the hole might not necessarily constitute a sufficient description of the effectiveness of the shot, although this type of information would be a valuable supplement to data on the actual fracturing effects.

The situation is similar with regard to the question of determining the maximum pressures created by the explosion. While a knowledge of these pressures would not in itself make possible a quantitative prediction of the actual fracturing to be expected under different conditions of shooting, it may be useful as a correlating guide in the interpretation of the observed effects resulting from the various shooting experiments.

Experiments could also be performed to give information regarding the effect of the distribution of the shot in the hole. Thus it is quite possible that when a thick pay zone is to be shot, the quantity of explosive required to produce a given effect might be reduced by separating the charge into two or more parts. Such a procedure might perhaps complicate the shooting problem to the extent that in order to achieve the desired results it would be more economical to increase the amount of explosive and place it in a continuous column. If on this account it should not be feasible to divide the charge, a given number of quarts can be

placed in small shells throughout the entire pay section or in large shells over a part of the pay. Experience seems to indicate that the latter practice is preferable. Granting this to be true, there remains the question as to whether the charge should be placed at the top, bottom, or middle of the pay.

A related question concerns the comparison between the effectiveness of a single large shot and a number of separate smaller shots. This, too, could be studied by direct field experiments.

If an experimental program to investigate this problem should be inaugurated, careful and complete records of each shot should be taken. Such records should include, of course, dimensions of hole, quantity and distribution of explosive, kind and quantity of stemming, and casing program. Also, in order to compare the effectiveness of different tests, the productivity factor should be measured before and after shooting but before acidization. The height of the fluid column would also be important.

It is to be understood, of course, that no rigid program can be outlined in advance for such experimental work. The experiments themselves, as they are performed, undoubtedly will indicate the way in which additional information could be most effectively acquired. However, some such field experiments as suggested above will be necessary to supplement the qualitative physical pictures developed here, before it will be possible to achieve any scientific control over the well-shooting process.

Acknowledgments

The authors are indebted to Mr. P. H. Bohart for suggesting this problem and appreciate the opportunity of discussing with him and Dr. B. B. Wescott many of its aspects. They also appreciate the constructive comments of Mr. G. C. MacDonald and his criticisms of the original manuscript. They wish to thank Dr. Paul D. Foote, Executive Vice-President of the Gulf Research and Development Co., for permission to publish this paper.

APPENDIX

Section 1

In the text it was emphasized that the time rate of pressure build-up was of considerable importance in determining the magnitude of the resulting stresses. The analytical basis for these statements and for the numerical values given is presented in the following paragraphs.

Specifically, the problem considered here is that of finding the stress distribution in an infinite medium resulting from the application of a radial pressure to the boundary of a spherical cavity within the medium. The pressure is given as a function of time but at any specified instant is uniform over the boundary. In particular, the boundary pressure, P, will be taken as $P = 0$ for $t < 0$, and $P = P(t)$ for $t > 0$. The application of pressure to the boundary will initiate a disturbance, which will travel radially outward at a velocity characteristic of the medium. Because of the symmetry of the boundary pressure, the disturbance will be one of pure dilatation with only radial displacements, so that the shearing stresses vanish.*

If polar coordinates with origin at the center of the cavity are adopted, the dilatation Δ is described by the differential equation:

$$\frac{1}{r}\frac{\partial^2}{\partial r^2}(r\Delta) = \frac{1}{v^2}\frac{\partial^2\Delta}{\partial t^2} \qquad [1]$$

where v is the longitudinal wave velocity of the medium. Relations between the dilatation, radial stress S, tangential stress T, and radial displacement U are given by the equations:

$$\Delta = \frac{1}{r^2}\frac{\partial}{\partial r}(r^2 U); \qquad S = \lambda\Delta + 2\mu\frac{\partial U}{\partial r};$$
$$T = \lambda\Delta + 2\mu\frac{U}{r} \qquad [2]$$

where λ and μ are the Lamé constants.

Suitable solutions of Eqs. 1 and 2 are given by:

$$\Delta = \frac{1}{r}\frac{\partial^2 F}{\partial r^2} \qquad [3]$$

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* A similar problem has been solved in a somewhat different manner by K. Kawasumi and R. Yosiyama.[10]

and

$$U = \frac{1}{r}\frac{\partial F}{\partial r} - \frac{F}{r^2} \qquad [4]$$

where F is any function of r-a-vt. The radial stress S will then be given by:

$$S = \frac{\lambda + 2\mu}{r}\frac{\partial^2 F}{\partial r^2} - \frac{4\mu}{r^2}\frac{\partial F}{\partial r} + \frac{4\mu F}{r^3}$$
$$= \frac{\lambda + 2\mu}{v^2 r}\frac{\partial^2 F}{\partial t^2} + \frac{4\mu}{vr^2}\frac{\partial F}{\partial t} + \frac{4\mu F}{r^3} \qquad [5]$$

When $r = a$, S becomes equal to the boundary pressure $P(t)$ and Eq. 5 becomes a differential equation, which may be used to determine $F(t)$.

Omitting the details of this step, it is easily verified that if F is taken as:

$$F = \frac{va^2}{8\pi\mu\sqrt{J-1}}\int_0^{\infty} P(\alpha)d\alpha \int_{-\infty}^{\infty}\left[\frac{1}{\omega + \frac{2v}{Ja}(i + \sqrt{J-1})} - \frac{1}{\omega + \frac{2v}{Ja}(i - \sqrt{J-1})}\right] e^{i\omega(\alpha - t')}d\omega \qquad [6]$$

where $J = (\lambda + 2\mu)/\mu$ and $-vt' = r$-a-vt, the right member of Eq. 5 reduces to the Fourier integral for $P(t)$ when $r = a$. For $r > a$, S and T may be calculated from Eqs. 2. The second integral in Eq. 6 is discontinuous and for $\alpha > t'$, it is identically zero. If the integration with respect to ω is carried out, F reduces to:

$$F = \frac{iva^2}{4\mu\sqrt{J-1}}\int_0^{t'} P(\alpha)\left[e^{2v(1+i\sqrt{J-1})(\alpha-t')/Ja} - e^{2v(1-i\sqrt{J-1})(\alpha-t')/Ja}\right]d\alpha. \qquad [7]$$

Since by definition $P(\alpha) = 0$ for $\alpha < 0$, F will vanish for $t' < 0$; that is, for $r - a > vt$. This means that the front of the disturbance is propagated radially with the velocity v. The time elapsed after the arrival of the front of the disturbance at any point r is given by $t - (r - a)/v = t'$. If $P(\alpha)$ is given as a pulse so that $P = 0$ for values of α greater than, say, τ, the upper limit of integration in Eq. 7 becomes τ, if $t' > \tau$; that is, if $t - \tau > (r - a)/v$. Under these conditions, the value of F represents the "tail" of the disturbance.

Applying this analysis to the special case in which the boundary pressure is given by:*

$$\left.\begin{aligned} P &= 0 \text{ for } t < 0 \\ P &= P_0(e^{-kt} - 1) \text{ for } t > 0 \end{aligned}\right\} \qquad [8]$$

the corresponding F, as calculated from Eq. 7, is found to be:

$$\frac{4\mu F}{P_0 a^3} = \frac{4v^2 e^{-kt'}}{Ja^2k^2 - 4kav + 4v^2} - 1 + \frac{e^{-2vt'/Ja}}{Ja^2k^2 - 4kav + 4v^2}\left[(Ja^2k^2 - 4kav)\cos\frac{2v}{aJ}\sqrt{J-1}\,t' + \frac{(Ja^2k^2 - 4kav + 2Jakv)}{\sqrt{J-1}}\sin\frac{2v}{Ja}\sqrt{J-1}\,t'\right] \qquad [9]$$

for $t > (r - a)/v$. For $t < (r - a)/v$, F is identically zero. It should be noted that F and its derivatives are functions only of the time elapsed after the arrival of the disturbance. The expressions for the stresses S and T will therefore each contain a term that decreases as $1/r$ rather than $1/r^3$, which alone occurs in the static case. The value of r at which these terms begin to become important will in general depend upon k.

By assigning numerical values to the constants in the resulting expressions for S and T, the stresses, as functions of t', were calculated for a number of values of r. For each value of r, the maximum stresses were determined graphically. Curves showing the maximum stresses as functions of r are plotted in Fig. 1. The numerical values of the constants were: $v = 10{,}000$ ft. per sec. and $J = 3$. This value of J corresponds to a Poisson's ratio of 0.25. Calculations were made for $k = 2 \times 10^4$ and $k = \infty$. For purposes of comparison, the stresses due to a static boundary pressure are also plotted.

Section 2

A problem, which arose in connection with the discussion of the effect of tamping in the creation of horizontal fractures, is that of finding the stress distribution in an infinite medium due to the application of static forces to the walls of a spherical cavity within the medium. The solution of this problem is given below. In particular, it will be assumed that a

* Although this value of P will not give convergence when used in a Fourier integral, the integral of Eq. 7 does converge. If P is taken as $P_0 e^{-\epsilon t}(e^{-kt} - 1)$, and the limit taken as ϵ approaches zero, this difficulty is avoided.

uniform radial pressure is exerted over one-half of the spherical boundary and that the pressure on the other half of the boundary is zero.

It is convenient to choose polar coordinates, r, θ, and Φ, with the origin at the center of the cavity, and to apply pressure over that part of the boundary included between $\theta = 0$ and $\theta = \pi/2$. Obviously all stresses and displacements will then be independent of Φ. For such a system the differential equations of equilibrium are:

$$(\lambda + 2\mu)\frac{\partial \Delta}{\partial \theta} + \mu \frac{\partial}{\partial r}\left[\frac{\partial}{\partial r}(rV) - \frac{\partial U}{\partial \theta}\right] = 0 \qquad [1]$$

$$(\lambda + 2\mu) r \sin\theta \frac{\partial \Delta}{\partial r} - \mu \frac{\partial}{\partial \theta}\frac{\sin\theta}{r}\left[\frac{\partial}{\partial r}(rV) - \frac{\partial U}{\partial \theta}\right] = 0 \qquad [2]$$

where U and V denote the displacements in the r and θ directions respectively, and Δ represents the dilatation. The relation between Δ, U, and V is given by:

$$r^2\Delta \sin\theta = \frac{\partial}{\partial r}(r^2 U \sin\theta) + \frac{\partial}{\partial \theta}(rV \sin\theta). \qquad [3]$$

The stresses in terms of Δ, U, and V are given by:

$$\left.\begin{aligned}
\sigma_r &= \lambda\Delta + 2\mu \frac{\partial U}{\partial r} \\
\sigma_\theta &= \lambda\Delta + 2\mu \left[\frac{1}{r}\frac{\partial V}{\partial \theta} + \frac{U}{r}\right] \\
\sigma_\Phi &= \lambda\Delta + 2\mu \left[\frac{V \cot\theta}{r} + \frac{U}{r}\right] \\
\tau_{r\theta} &= \mu \left[\frac{\partial V}{\partial r} - \frac{V}{r} + \frac{1}{r}\frac{\partial U}{\partial \theta}\right]
\end{aligned}\right\} \qquad [4]$$

where σ_r, σ_θ, and σ_Φ, denote the components of compression or tension, and $\tau_{r\theta}$ the shearing stress.

If the radius of the spherical cavity be taken as unity, the boundary conditions require that:

$$\tau_{r\theta} = 0 \text{ for } r = 1; \quad \sigma_r = p \text{ for } r = 1, \quad 0 < \theta < \frac{\pi}{2};$$

$$\sigma_r = 0 \text{ for } r = 1, \frac{\pi}{2} < \theta < \pi \qquad [5]$$

where p is the unit stress applied in the cavity. The fact that the cavity was assumed to have unit radius results in no loss of generality since by substituting r/a for r in the final expressions for the stresses, one obtains the stress distribution around a cavity of radius a.

The method of obtaining solutions for Eqs. 1, 2 and 3 satisfying the boundary conditions implied in Eqs. 4 and 5 is straightforward and the details will not be given here. U, V, and Δ are found to be given as series in powers of $1/r$ and Legendre polynomials P_n, in $\cos\theta$, and the coefficients in these series are determined from

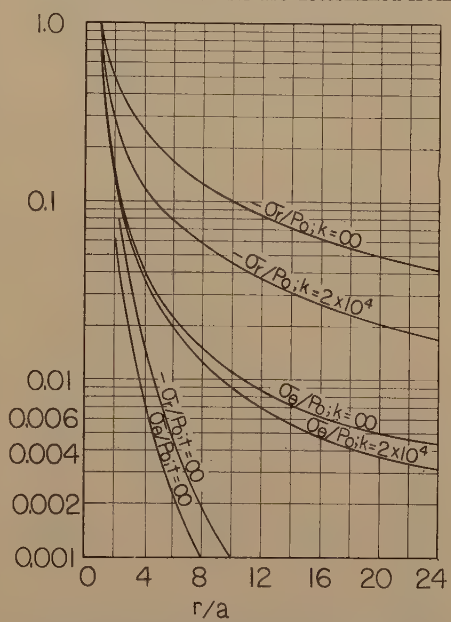

FIG. 1.—STRESS DISTRIBUTION IN AN INFINITE MEDIUM RESULTING FROM THE APPLICATION OF A VARYING PRESSURE $P = P_0(e^{-kt} - 1)$ TO THE WALLS OF A SPHERICAL CAVITY OF RADIUS a.

σ_r and σ_θ represent the maximum values attained by the radial and tangential stresses, respectively.

r = distance from the center of the cavity.

The two lower curves, for $t = \infty$, represent the case where a static pressure P_0 is applied in the cavity.

Longitudinal wave velocity = 10,000 ft. per second.

the Legendre expansion of the boundary stress. The resulting expressions for the stresses are:

$$\frac{\sigma_r}{p} = \sum_n \left[\frac{(R-1)(n^3+3n^2-n)+n}{r^{n+1}} - \frac{(n+1)\{R(n^2-1)-n^2\}}{r^{n+3}}\right] A_n E_n P_n(\cos\theta)$$

$$\frac{\sigma_\theta}{p} = \sum_n \left[\frac{n(n-1)^2 - n^2(n-2)R}{r^{n+1}} + \frac{(n+1)^2\{R(n^2-1)-n^2\}}{(n+2)r^{n+3}}\right] A_n E_n P_n(\cos\theta) - \sum_n \left[\frac{R(n-2)-n}{r^{n+1}} - \frac{R(n^2-1)-n^2}{(n+2)r^{n+3}}\right] A_n E_n \cot\theta \frac{dP_n}{d\theta}$$

$$\frac{\sigma_\varphi}{p} = \sum_n \left[\frac{R(n^2 - 2n) - 3n^2 + n}{r^{n+1}} + \frac{(n+1)\{R(n^2-1) - n^2\}}{(n+2)r^{n+3}} \right] A_n E_n P_n(\cos\theta) + \sum_n \left[\frac{R(n-2) - n}{r^{n+1}} - \frac{R(n^2-1) - n^2}{(n+2)r^{n+3}} \right] A_n E_n \cot\theta \frac{dP_n}{d\theta}$$

$$\frac{\tau_{r\theta}}{p} = \sum_n \left[\frac{R(n+1) + n}{r^{n+1}} + \frac{R(n^2-1) - n^2}{r^{n+3}} \right] A_n E_n \frac{dP_n}{d\theta}$$

where $R = (\lambda + 2\mu)/\mu$, $1/A_n = R(2n^2 + 1) - 2n(n-1)$

$E_0 = \frac{1}{2}$, $E_n =$

$$(-1)^{(n-1)/2} \frac{2n+1}{2n+2} \frac{(n-1)!}{\left[\left(\frac{n-1}{2}\right)!\right]^2 2^{n-1}} \text{ for odd } n$$

and $E_n = 0$ for n even and > 0.

These expressions for the stresses are rather complicated but with the exception of $\tau_{r\theta}$ reduce to very simple formulas for the special case of $\theta = \pi/2$. Since the E_n are zero for all even values of n except zero, the expressions for the stresses will contain, except for $n = 0$, only odd terms. For odd values of n, P_n, and $\cot\theta \frac{dP_n}{d\theta}$ vanish at $\theta = \pi/2$. Therefore, at $\theta = \pi/2$, the stresses reduce to:

$$\sigma_r = p/2r^3; \qquad \sigma\theta = \sigma_\varphi = -p/4r^3 \qquad [6]$$

$\tau_{r\theta}$ does not reduce to such a simple form but for $\theta = \pi/2$ is given by:

$$\tau_{r\theta} = p\left[-\frac{0.083}{r^2} + \frac{0.302}{r^4} + \frac{0.050}{r^6} + \frac{0.017}{r^8} + \cdots \right] \qquad [7]$$

It can be shown that $\tau_{r\theta} \to 0$ as $r \to 1$ for all values of θ except $\theta = \pi/2$. For $\theta = \pi/2$, the limit approached by $\tau_{r\theta}/p$ is approximately 0.3.

Eq. 6 forms the analytical basis for the discussion of the effect of tamping beginning on page 220.

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DISCUSSION

G. C. MacDonald,* Tulsa, Okla.—The paper by Evinger and Muskat is self-limiting to a consideration of the fracturing of subsurface strata and possible damage to casing, but these two subjects embrace nearly all of the beneficial and detrimental results of oil-well shooting. In discussing the explosion process, the idea is advanced that the first application of pressure to the walls of the hole is the result of the decomposition of the explosive because the velocity of detonation will be greater than the velocity of pressure equalization of the end products of explosion or the velocity of pressure wave through the surrounding fluid. It is true that the wave of detonation will travel from one end to the other of a 100-ft. column of nitroglycerin in a very short time, probably 1/200 of a second. However, if both the explosive and the surrounding fluid are vaporized at least momentarily immediately behind the detonation front, a tremendous pressure is generated. Whether or not this pressure build-up will lag behind or precede the detonation front is rather important. If the statement made in the paper is true, that this pressure build-up will lag behind the detonation front and hence each increment of explosive will decompose under conditions identical with those under which the next increment above decomposed, the shattering action of the explosive should be uniform over the entire length of the explosive column. However, if the pressure build-up does precede the detonation front, each increment of explosive will fire under a higher temperature and pressure than the next preceding increment. Under this latter condition, it would be reasonable to expect the greatest consequences of the shot to occur at the bottom of the hole.

The development of a pear-shaped shot hole by a solid-stemmed nitroglycerin shot has been

* Gulf Oil Corporation.

accepted as a fact by many authorities. Experience in dumping solid explosive in old shot holes and observation of clean-out activities following solid stemmed shots has thoroughly convinced me that a pear-shaped shot hole is formed under a solid stemmed shot. This leads to the logical conclusion that the action of the explosive is not uniform over the entire length of the explosive column and that, therefore, there may be some change in the conditions of temperature and pressure under which the lower portion of the explosive column fires. It would appear reasonable to assume a greater shattering action from a unit quantity of explosive detonating in a condition of previously imposed high pressure.

If the cause of the pear-shaped hole could be determined, possibly steps could be taken to eliminate it. Usually water is an ever present hazard in the lower portion of a producing structure and the deliverance of the maximum shattering effect of the shot in the lower portion of the borehole may shoot the well into water. If the maximum effect of the shot could be removed from the lower portion of the borehole and directed against the objective beds, a long step forward in shot design would be effected. In searching for the cause of these shot phenomena, it should be borne in mind that nearly always the explosion is initiated at the top of the explosive column, hence the maximum shot effect occurs at the opposite end of the column, or in the direction of detonation travel. If the shot were placed some distance below the casing shoe, and if it could be confined sufficiently, possibly the bomb might be placed at the bottom of the explosive column, but the consequences of directing the added energy toward the casing shoe are not particularly attractive.

In considering the pressure in the borehole developed by the explosive, it is true, as stated in the paper, that it is almost impossible to confine gases under any such pressure as 1,000,000 lb. per sq. in., but again the element of time influences and qualifies this concept. The gaseous end products of explosion and the vaporized fluid in the borehole will exhibit a sensible inertia, and until those gases are accelerated and started out into the confining rock, an astronomical pressure may in fact exist momentarily. The gases are in the borehole and their presence generates pressure, no reduction in pressure will occur until they have left the borehole; before they can get away the inertia of the gas and the fluid in the rock pores that the gas will subsequently occupy must be overcome. Each unit volume of nitroglycerin will generate 749 times its own volume of permanent gases on decomposition, and when these permanent gases are added to the vapors of the surrounding fluid and all elevated to some 3000°C., a considerable volume of fluid must be removed from the rock pores to accommodate these dispersing gases. Even though the time required to accelerate this material may be small, still, until it is accomplished, the pressure is there.

Each shot placed involves a decision as to the type of explosive to be used, the quantity of explosive, the size of the shells, and whether the shot is to be solid-stemmed or liquid-stemmed. At times there are few real data upon which to make a decision and it is difficult to justify a position assumed. In the choice of explosive, the 100 per cent gelatin offers such obvious advantages of safety in handling that it is high in favor. It may or may not be adapted to the particular formational conditions assumed to exist in the well to be shot, but until the action of explosive on the rock and the reaction of the rock to the explosive are better understood a truly satisfactory selection of explosive cannot be made. Muskat and Evinger have made a real contribution to the fund of knowledge on this important subject. They have shown that because of the importance of the time rate at which the pressure is applied, the explosive that develops its maximum pressure in the shortest time will be productive of the greatest fracturing action in the confining rock. The day when explosive may be selected on a sound basis has been brought substantially closer.

The quantity of explosive and the size of the shells are interrelated and admit of much less variation today than was possible a few years ago. The current practice of running small-diameter casing, with the resultant small-diameter borehole through the objective beds, does not permit a great deal of latitude in the selection of shell sizes. If the explosive is to be confined to the portion of the hole opposite the objective beds, a further limitation on shot design is imposed. The authors have shown that in a spherical cavity the fracturing radius

varies as the cube root of the size of the charge for static pressure conditions and as the first power of the size of the charge when the time rate at which the pressure is applied is considered. This is a very important and fundamental consideration; it means that increasing the shell size from 3 in. to 4½ in. should result in an approximate doubling of the fracturing radius of the shot; it does not mean that two 3-in. shells placed one on top the other will be any more effective than one.

The question of whether to solid-stem or fluid-stem a shot is constantly recurring. The technicians of the explosive companies have probably been as instrumental as anyone in the relatively recent acceptance by the oil industry of solid stemming. Experience in mine and quarry blasting provided a sound basis for their advocacy of this practice, and while it often meant that less explosive would be used in a given shot, at the same time it provided a means by which other wells could be safely shot, whereas without solid stemming certain disaster to the casing would result. Solid stemming itself is not unduly expensive, but the expense of removing it following shot detonation may be high. A fluid-stemmed shot could conceivably allow the hole to unload and clean itself upon shot detonation, so that the well could almost immediately be placed on production, but removal of solid stemming may be both expensive and hazardous. If every well could be safely and effectively shot with fluid stemming, the additional explosive necessary to develop a comparable shot effectiveness would be a reasonable investment, but at least two mechanical considerations transcend the economic viewpoint. Often in the Mid-Continent area the top of the shot must be so close to the casing shoe that damage to that shoe would surely result upon detonation of a fluid-stemmed shot. Sizable shots 3 and 4 ft. below the shoe are not uncommon today and this, of course, would be impossible without solid stemming. The second mechanical consideration is that of a rock so elastic or tough that a fluid-stemmed shot would be ineffective in developing desirable fractures; this condition, too, would indicate a solid-stemmed shot. If the beneficial results of the shot could not be expected to pay out the increased cost of the solid stemming under these two conditions, the shoe should be abandoned, not fluid-stemmed.

If solid stemming is indicated, the quantity and type of material to be used merits careful consideration. A high degree of frictional coupling of the stemming material with the confining walls is desirable in the open hole but might impose concentrated stresses in the pipe if it were to be developed in the casing. Pea gravel is a good medium inside the case because it should not develop an excessive degree of frictional coupling, but it is difficult to place without bridging and hazardous to remove. Recently gypsum cement has gained wide favor as a solid-stemming material, its preference over Portland cement resulting solely from its greater rapidity of set and rate of strength gain. Under comparable conditions, it will develop in from 3 to 4 hr. the compressive strength that for Portland cement requires 24 hr. It is much safer to remove with a sand pump than is pea gravel, because the possibility of sticking the pump is much less.

The quantity of solid-stemming material to be used has been the subject of much discussion and controversy. Various attempts have been made to develop an empirical method of determining it, based primarily on the quantity of explosive used, but have not been successful because quantity of explosive plays a relatively minor part in the design of a solid-stemming structure. It is fairly obvious that if the shot is to be confined the stemming must present a greater resistance to impact than the objective beds; the shot energy is dissipated through the channel of least resistance and if that channel is the solid stemming the shot will not be confined. However, if the objective beds offer the least resistance to failure, the shot will be confined. It is fairly obvious that the relative resistance to impact failure presented by the solid stemming and the objective beds is not primarily a function of the quantity of explosive used. Solid stemming over a given shot opposite certain sands has completely confined that shot, whereas the same solid structure over an identical shot in a tough dolomite has allowed the fluid in the casing above that structure to play an unbroken stream over the crown blocks for several minutes. Solid stemming design should be predicated primarily on the character of the objective beds and only secondarily upon quartage of explosive.

Fortunately, in a given field most wells produce from the same rock and it is possible to determine quickly the quantity and type of solid stemming necessary to completely confine a nitroglycerin shot opposite a producing section. Careful observation of the action of the fluid in the casing upon detonation of each shot, and an exact record of the quantity and position of all material in the hole, will soon develop the background needed for a satisfactory working basis of stemming design. Complete confinement may not always be advisable; if increased explosive efficiency is the object of stemming, a relatively small amount of stemming may suffice, but if casing protection is the objective the ends will be much better served by striving for complete confinement. The energy necessary to accelerate whatever material is in the hole above the shot is a measure of the magnitude of the blow directed against the objective beds, and the force necessary to start in upward movement even a small amount of material is considerable. Everyone is familiar with the consequences of firing a shotgun with even the slightest obstruction in the barrel, and this condition is analogous to oil-well shooting.

The inability to observe first hand the results of the application of nitroglycerin on the confining rock in the borehole necessitates an analytical approach to the problem of shooting. After a well has been shot in a given manner, it is almost futile to try to say what the consequences might have been if the well had been shot in some other manner. An experimental field shooting program such as has been suggested might be valuable if large contiguous holdings made possible sufficient shots to establish at least mode results, if mean results could not submerge occasional inconsistencies. However, no two wells ever were drilled into a given rock of identical characteristics, in a given manner and under identical conditions. For the present it would appear that the greatest possibility of advancement lies in the field of analytical investigation of the caliber presented by the authors of the paper under discussion. It may be that at some time in the future a field condition could be developed that would lend itself to an experimental field shooting program and under those conditions the program might be entered into with some assurance of beneficial results.

Effects of Pressure and Temperature on Condensation of Distillate from Natural Gas

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(Tulsa Meeting, October 1940)

Deep drilling has led to the development of numerous pools which yield products consisting predominantly of natural gas accompanied by high-gravity water-white or slightly straw-colored liquid. Yields of this "condensate" or "distillate," as it is commonly called, vary from traces to over a hundred barrels per million cubic feet of gas. The fact that this liquid exists in the reservoir as an integral part of the gas phase and is formed by condensation attending simultaneous reduction of pressure and temperature after its entry into the well was apparently first recognized about 1932.[1] The nature of the physical phenomena involved in this condensation was clarified for the petroleum industry in 1933 by a report by Sage, Schaafsma, and Lacey[2] of the results of an experimental investigation of the behavior of mixtures of methane and propane.

Search of the literature has revealed that the condensation of liquid from gaseous mixtures by isothermal pressure reduction is not a new discovery. Kuenen was led by theoretical considerations to expect such a phenomenon, and in 1892 reported[3] the results of experimental verification of his deductions. This was followed by a considerable amount of work on the phase relations of mixtures by Kuenen[4,5,6] and by others,[7,8] mostly in European universities. Since 1930 investigators in this country have reported experimental data on the properties and behavior of a number of hydrocarbon systems.[9–17]

It is now generally known that in the presence of natural gas the solubility in the gas phase of the heavier and normally liquid hydrocarbons increases rapidly with increasing pressure above 500 to 1000 lb. per sq. in. Thus, at pressures of 2500 lb. per sq. in. or higher a gas may contain appreciable quantities of hydrocarbons with normal boiling points as high as 600°F., which in turn may be condensed from the gas phase by the reduction of their solubility therein attending pressure reduction. The combined effects of pressure and temperature on condensation and vaporization of mixtures are most readily visualized by the study of phase diagrams. Since the construction, application, and interpretation of such diagrams have been described fully in readily available literature,[18–20] this paper will not review the theoretical aspects of this subject.

While the behavior of gas-distillate systems is now clearly understood, at least in a qualitative way, most of the published work deals with the results of laboratory studies of binary systems or of synthetic mixtures of hydrocarbons, and although several systematic investigations of the effects of separator pressure and temperature on the yields of liquid product from gas-distillate wells have been made[21,22] it appears that in all cases the limitations have precluded the construction of even approximately complete phase diagrams for naturally occurring systems. There has

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* Humble Oil & Refining Co., Houston, Texas.

[1] References are at the end of the paper.

been a tendency, therefore, for investigators to interpret their observations in relation to oversimplified phase diagrams of simple mixtures and to fail to appreciate fully some of the implications involved in dealing with the complex mixtures that issue from gas-distillate reservoirs.

With the object of obtaining quantitative information on the limitations attending the recovery of distillate from natural gas by the control of the temperature and pressure of separation, a pilot plant was built and operated some years ago to process over a pressure range of 0 to 2000 lb. per sq. in. at temperatures of $-40°$ to $+80°$F. about 500 M cu. ft. of gas per day taken directly from the tubing of a gas-distillate well producing from the gas cap of a 6000-ft. oil field. Liquid and gas volumes were measured, samples taken for hydrocarbon analysis, and the gasoline content of the residue gas determined by charcoal adsorption. The information obtained with this plant showed clearly that the material produced from the well existed in the reservoir wholly as gas. In order that similar investigations might be made in other fields and information be obtained which might eventually permit calculation of the behavior of such systems from a limited amount of experimental data, a portable plant was built, retaining the same operating principles as the original pilot plant, but improved in construction and in control facilities. This paper describes the operation of this experimental plant and the results obtained on a typical gas-distillate well producing from approximately 10,000 ft. The results are interpreted in the light of similar data obtained in other fields.

Construction and Operation of Experimental Equipment

The method used in these investigations consisted of sampling through a small tube an aliquot portion of the material produced from a well, passing the gas and any condensed hydrocarbons into a separation chamber maintained at controlled temperature and pressure, measuring the resultant liquid and gas volumes, and removing samples of both liquid and gas for hydrocarbon analysis.

Sampling Connections

The sampling connections consisted of a straight section of stainless-steel tubing, usually ¼ in. o.d., with the lower end honed to a long taper terminating in a razor edge. The upper end was flared to fit a compression fitting in a specially constructed ½-in. bushing, which is screwed into the bull plug customarily found at the top of a Christmas tree. The length of the tube is adjusted for any particular well so that it ends in a straight vertical section below the flowline connection. In order to obtain a true aliquot portion of the well fluids, the sampling rate is adjusted to bear the same ratio to the total gas flow as the ratio of the cross-sectional area of the sampling tube to that of the pipe from which the stream is taken. Whenever possible, the sampling rate is checked by comparison of the yield obtained with the experimental separator and that measured in a full-size separator simultaneously processing the remainder of the production.

Experimental Plant

A flow diagram of the experimental separator assembly is shown in Fig. 1. The wet gas from the well passes at well-head pressure through an inlet scrubber of 2½-in. hydraulic pipe 24 in. long, for the separation of entrained water and condensate. The bottom of the scrubber is equipped with a short trap of 1-in. pipe with connections for separate removal of water and of condensed hydrocarbons. From the top of the scrubber the gas flows without pressure reduction to the bottom of a drying chamber 2.3 by 24 in. inside, packed with granular calcium chloride held in a porous cloth sack. From the

drier the high-pressure gas flows countercurrent to cold residue gas through 25 ft. of ¼-in. o.d. copper tubing coiled within ½-in. o.d. copper tubing enclosed within recombined with the liquid hydrocarbons from the first scrubber and expanded into a short length of ¼-in. copper tubing terminating in a half coil at the mid-point

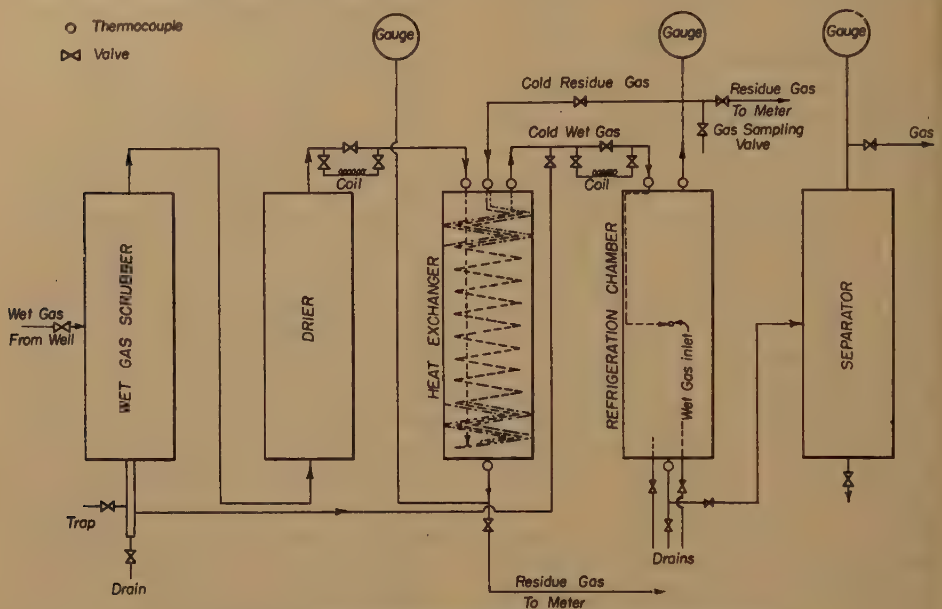
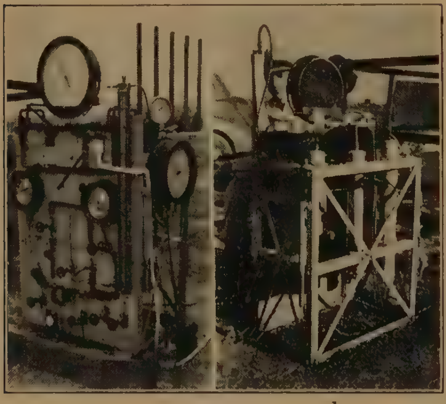


FIG. 1.—FLOW DIAGRAM OF EXPERIMENTAL SEPARATOR ASSEMBLY.

a 2¾ by 24-in. high-pressure chamber, into which the lower end of the ½-in. coil is



a *b*

FIG. 2.—EXPERIMENTAL SEPARATOR ASSEMBLY: *a*, FRONT; *b*, REAR.

open. The gas and any condensed liquid from the heat exchanger are continuously of a refrigeration chamber, into which they are discharged with a circular motion. The refrigeration chamber is 3¼ by 24 in. inside, with the upper part packed with shredded copper to promote coalescence of liquid droplets. It serves both as the separator for the condensed liquid and the residue gas and as a measuring and sampling cell. Residue gas from the refrigeration cell returns to the heat exchanger to precool the incoming wet gas, whence it is expanded into a joint of 2-in. pipe for metering. In the lower part of the refrigeration chamber are three drains, one at the bottom, and two, of 3/16-in. o.d. copper tubing, terminating at 2 in. and 4 in. from the bottom. The liquid from the refrigeration cell may be expanded into a small separator of 2½-in. pipe 15 in. long, whence it may be drained for measurement after release of the dissolved gas.

The heat exchanger, refrigeration cell, and all valves and fittings subjected to low temperature are made of high-nickel, shock-resistant stainless steel and are insulated with cork coverings; other valves and fittings are of ordinary steel. Connecting tubing between the various vessels is ¼-in. o.d. seamless stainless steel with flared ends and compression fittings. All units are mounted compactly within a single iron framework, with the pressure gauges, control valves, thermocouple connections, etc., mounted on a solid control panel at the front. Photographs of the plant are shown in Fig. 2.

Temperature, Pressure, and Volume Measurements

Temperatures of the wet gas entering the heat exchanger, leaving the heat exchanger, and entering the refrigeration cell after expansion; of the residue gas leaving the refrigeration cell and entering and leaving the heat exchanger; and of the liquid in the refrigeration chamber are measured by means of copper-constantan thermocouples with the junctions inserted for several inches into the tubing carrying the flowing streams. The insulated lead wires were packed with Bakelite cones in compression fittings.

The pressure in the refrigeration chamber is measured with a calibrated 5000-lb. per sq. in. Heise steel-tube bourdon gauge with a 12-in. dial graduated in 10-lb. divisions. Other pressures are measured with ordinary calibrated test gauges.

The residue gas is metered with an orifice well tester screwed directly to the end of a joint of 2-in. pipe. To facilitate control and to prevent freezing and surging, the residue gas is sometimes passed through an auxiliary length of ¼-in. copper tubing prior to its entry into the 2-in. pipe.

The amount of liquid condensed in the refrigeration chamber is determined by measuring with a stop watch the time required for the liquid level to rise from the middle to the top drain, the volume between which has been determined by calibration. The measurement is made by barely opening the valve to the middle drain, withdrawing liquid from the bottom drain until the level is below the middle drain, adjusting the valve to the middle drain until the hiss of escaping gas is just distinctly audible, and then closing the bottom valve. When the liquid reaches the level of the drain, the tone of the hiss suddenly changes, signaling the time for the start of the measurement. The middle valve is immediately closed and the valve to the top drain is opened in a similar manner to permit a small gas leak until the liquid reaches this drain. These measurements are repeated until satisfactory checks are obtained.

Experimental Procedure

Well Tests

The well chosen for the tests described in this paper was producing from approximately 10,000 ft. with a subsurface pressure of 5040 lb. per sq. in. gauge and reservoir temperature of 178°F. No oil has been found in this sand. The yield averaged approximately 16 bbl. per million cubic feet of 48° to 50°A.P.I. distillate recovered in the stock tanks after low-pressure separation.

After preliminary experiments indicated that liquid was condensed in the well bore during flow, the well was produced through 2½-in. tubing into a calibrated full-scale separator at various rates, to determine the flow velocity required to keep the condensed liquids flowing continuously out of the well. It was found that at a rate above 1¾ to 2 million cu. ft. of gas per day the liquid yield in the separator was substantially constant. Thereafter, during all tests with the experimental plant the well was produced continuously at a rate of

approximately 3 million cu. ft. per day with approximately 20,000 cu. ft. per day sampled.

In order to check the sampling rate through the experimental plant, several runs were made at 125 lb. per sq. in. and the yield compared with that obtained by the full-scale separator operating at the same pressure. The results checked within the limits of reproducibility of the full-scale yields, approximately 5 per cent.

During the entire series of tests the well-head pressure averaged 3980 lb. per sq. in. gauge. At this pressure, at the average temperature of 82°F. in the first scrubber, 0.3 gal. of distillate and 0.008 gal. of water containing 10,200 p.p.m. chloride were condensed per 1000 cu. ft. of gas.

The gas was passed through the first scrubber at the tubing pressure and the water yield determined. Prior to each run the accumulated water was drained off, while during a run it was allowed to accumulate below the point of take-off of liquid hydrocarbons from the scrubber. The condensed liquid hydrocarbons by-passed the drier and the heat exchanger and were recombined with the main gas stream just before its expansion into the refrigeration separator.

The liquid yield in the separator was determined at a series of pressures ranging from 125 to 3980 lb. per sq. in. gauge and temperatures from −93° to +81°F. The pressure was controlled by simultaneous adjustment of the valves regulating the inlet and residue gas flow, and during a measurement of the rate of liquid formation was usually kept constant within approximately 10 to 20 lb. per sq. in. All temperatures below atmospheric were obtained by the cooling incident to expansion of the gas, augmented when necessary by pre-cooling the inlet gas prior to its expansion by heat exchange with the cold residue gas. The lowest operating temperatures were obtained by expanding the cold residue gas into the heat exchanger to obtain further pre-cooling. Temperatures as low as −166°F. were thus obtained on the low-temperature side of the heat exchanger. The higher temperatures were obtained by eliminating the pre-cooling, allowing the residue gas to by-pass the heat exchanger, and expanding the inlet gas into an auxiliary uninsulated 50-ft. coil of 3⁄16-in. copper tubing to permit its warming up to atmospheric temperature prior to its entry into the separator. Unfortunately, no heating facilities were available to permit tests above atmospheric temperature.

The residue gas leaving the refrigeration chamber averaged approximately 2°F. higher than the inlet gas at the subatmospheric temperatures. The temperature of the liquid varied somewhat with its rate of formation and with the operating temperature, averaging approximately 5°F. higher than the inlet gas temperature.

After measurement of the "gross" liquid with its dissolved gas at the temperature and pressure in the refrigeration cell, a measured quantity was flashed directly into narrow-mouthed quart glass bottles, warmed slowly and its volume and gravity determined. The liquid so obtained has been called the "net" product; it corresponds roughly to that which would be received in the ordinary stock tanks.

Samples for Hydrocarbon Analysis

Equilibrium gas and liquid samples for hydrocarbon analysis were taken from the refrigeration cell at three temperatures at pressures of 500, 1000, and 1500 lb. per sq. in. gauge.

The condensed liquid samples were taken by withdrawing directly from the refrigeration cell approximately 125 c.c. through the bottom drain into evacuated high-pressure sample drums of 600 c.c. capacity. During sampling, the liquid level in the separator was maintained at the middle drain and the quantity sampled determined

by the elapsed time and the previously determined rate of liquid formation.

Gas samples were taken directly from the residue gas line immediately above the refrigeration cell into evacuated high-pressure drums of 1200 c.c. capacity. In addition to the samples for conventional hydrocarbon analysis, triplicate gas samples were taken simultaneously through a common manifold into charcoal tubes. The charcoal was saturated to the fourth temperature rise[23] to retain the butanes and heavier materials. In order to prevent the loss of hydrocarbons condensed when the gas is expanded to atmospheric pressure, the gas was expanded directly into the bottoms of the charcoal tubes and metered after adsorption. The thermometers in the tops of the charcoal tubes were held in place with tight-fitting rubber stoppers. It was found that the temperature rises were more distinct if the charcoal tubes were insulated and shielded from the wind and sun.

Analytical Technique

Liquid Samples

All liquid samples taken at conditions that permitted resaturation at room temperature were resaturated by injecting mercury into the sample drums and agitating vigorously until the pressure in the drum considerably exceeded the saturation pressure. A convenient portion of the resulting homogeneous liquid was then charged to the fractionating column by mercury displacement at a pressure exceeding the saturation pressure. When the sampling temperature was such that resaturation was not feasible, the pressure in the drum was raised to 3000 lb. per sq. in. by mercury injection, the drum was agitated and the entire contents charged to the fractionating column by mercury displacement at 3000 lb. per sq. inch.

The liquid samples were charged from the drums through a small topping still to an automatic Podbielniak column. The topping still was heated after charging, to a sufficiently high temperature to pass the hexanes and lighter materials to the Podbielniak column with the heavier fractions retained by reflux. Analyses with the low-temperature column were carried through hexane. The residual liquid in the still was then recombined with that in the topping still and the quantity, molecular weight, and gravity were determined. Molecular weights were determined by the cryoscopic method, with benzene, extrapolating to zero concentration.

The heptanes, octanes, and nonanes in the residual liquid were determined with a specially constructed auxiliary column with a 5-ft. fractionating length and heated air jacket, using boiling pure liquids for constant overhead temperatures during distillation. The course of the distillation was followed by observation of the column pressure, with the products collected in small sample tubes immersed in liquid nitrogen. The overhead cuts were arbitrarily segregated into portions called heptanes, octanes, and nonanes for the appropriate boiling intervals. The specific gravity of the overhead cuts and the specific gravity and molecular weights of the residual liquid were determined.

Gas Samples

Gas samples were charged direct from the sample drums to the Podbielniak column by mercury displacement. Prior to charging, mercury was injected into the sample drums to raise the pressure to at least 2000 lb. per sq. in. above the sampling pressure and the contents were agitated to revaporize any condensate.

The charcoal samples were analyzed by two methods. One of the triplicate samples was used for determination of the isobutane and heavier content and the 20-lb. Reid vapor-pressure gasoline by the California Natural Gasoline Association method.[23] The contents of the second were analyzed

with the Podbielniak column. The auxiliary apparatus used for charging these samples to the fractionating column is shown in Fig. 3. The charcoal was placed in a round-

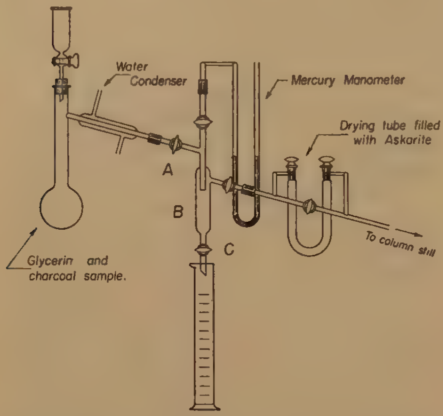


Fig. 3.—Auxiliary apparatus for charging charcoal samples to fractionating column.

bottom distillation flask equipped with a delivery tube and a dropping funnel with a stopcock. After evacuation of the Podbielniak column and the auxiliary apparatus back to stopcock *A*, c.p. anhydrous glycerin was admitted with the dropping funnel, with no heat applied. The liberation of hydrocarbons from the charcoal with the glycerin was vigorous and care had to be taken not to add it too rapidly. Methane and air were carried overhead on the Podbielniak column during the charging process, but sufficient reflux was carried to ensure complete retention of any materials heavier than propane. After sufficient glycerin had been added and the gas liberation had ceased, the temperature was raised gradually until glycerin refluxed in the neck of the distillation flask and 50 c.c. had been carried overhead and condensed in trap *B*. The stopcock *A* was then closed and the glycerin drained from trap *B* through stopcock *C*. Any hydrocarbons in trap *B* were then sucked into the Podbielniak still by connecting stopcock *C* directly to the inlet tube to the still.

Analyses with the Podbielniak column were carried through hexane and the quantity, specific gravity, and molecular weight of the residual liquid were determined.

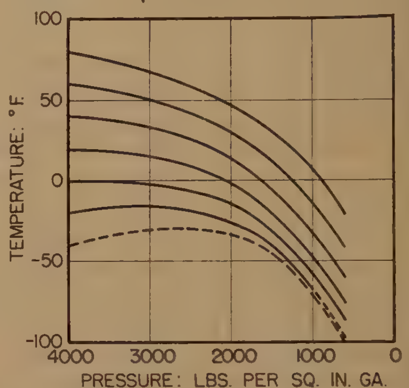


Fig. 4.—Cooling effect of expanding gas.

The composition of the sampled gas was calculated by dividing the determined quantity of each component by the sum of the volume of gas metered after passing through the charcoal plus the vapor equivalent of the adsorbed materials. The methane, ethane, and propane were grouped together, or were proportioned according to the relative quantities determined by the conventional analysis on a similar sample. The superiority of this method for determining the composition of lean gases may be appreciated from the fact that a conventional gas sample of normal size with 0.2 gal. per thousand of butanes and heavier will contain approximately 0.8 liquid c.c. of these materials, whereas a charcoal sample will usually contain from 15 to 30 liquid c.c. of butanes and heavier. The success of the method was found to depend to a large extent on the use of water-free charcoal and glycerin. Charcoal purchased in sealed cans was found satisfactory.

Data

The data on the cooling effect of the expanding gas are presented graphically in Fig. 4 as a series of curves showing the

temperature reached by expanding the gas from fixed initial temperatures and pressures. The cooling effect was most pronounced at low pressures, almost disappearing over the interval above 3000 lb. per sq. in. Below −20°F. there was apparently a reversal in the behavior, leading to a heating effect instead of a cooling effect at the higher pressures.

TABLE 1.—*Operating Conditions and Liquid Recovered*

Pressure, Lb. per Sq. In. Gauge	Temperature, Deg. F.	Liquid Production, Gal. per M Cu. Ft.		Gravity of Net Liquid, Deg. A.P.I. at 60°F.
		Gross	Net	
127[a]	48	0.84		50.6
127[a]	50	0.80		
127[a]	66	0.72		49.3
127[a]	72	0.75		49.1
125	50	0.77		
125	51	0.77	0.74	50.3
125	76	0.73		
500	−93	3.19		
500	−49	1.77	1.11	57.7
500	−16	1.40	1.01	55.8
500	80	0.91	0.82	49.6
800	81	0.91	0.76	50.0
1,000	−64	1.68	0.92	55.2
1,000	−49	1.95	1.03	55.9
1,000	12	1.21	0.89	53.6
1,000	77	0.97	0.72	49.4
1,250	−53	1.27	0.84	53.4
1,250	−36	1.54	0.89	54.1
1,250	22	1.18	0.84	51.6
1,250	80	0.98	0.76	49.6
1,500	−44	0.94	0.73	
1,500	−38	1.09	0.72	50.7
1,500	−17	1.43	0.90	51.8
1,500	38	1.08	0.78	51.0
1,500	81	0.96	0.71	49.3
2,000	−13	0.90	0.60	47.8
2,000	21	0.96	0.68	49.3
2,000	80	0.92	0.66	48.0
2,500	38	0.74	0.50	47.8
2,500	83	0.77	0.55	46.3
3,980	82	0.30	0.23	40.5

[a] Determinations with full-size separator processing 1.75 to 4.5 MM cu. ft. per day.

The experimental data on the effects of the temperature and pressure in the refrigeration chamber on the amount and gravity of the condensed liquid are presented in Table 1. The gross liquid volumes are as measured in the refrigeration chamber, including the dissolved gas, while the net liquid volumes are measured at 60°F. after release of the dissolved gas.

The results of the hydrocarbon analyses of the equilibrium gas and liquid samples withdrawn from the refrigeration chamber are presented in Table 2. The methane, ethane, and propane values on the gas samples were determined by the conventional analysis and the heaviers from the results on the charcoal samples. Two of the liquid samples at 500 lb. per sq. in. were lost.

The character of the heavier materials in the well effluent is indicated in Table 3, in which are presented the results of an A.S.T.M. distillation of the liquid flashed to atmospheric pressure from the run at 500 lb. per sq. in. and −49°F. At these conditions substantially all of the pentanes and heavier materials were condensed in the separator and the liberation of the dissolved gas was conducted at a temperature low enough to ensure retention of all materials heavier than hexane as well as a substantial portion of the intermediate hydrocarbons in the residual liquid.

Correlation and Interpretation of Results

Composition of Original Material

The composition of the material entering the well from the reservoir was calculated from the hydrocarbon analyses and the experimentally determined gas-liquid ratios. The calculated composition of the reservoir material is presented in Table 4. This analysis is probably accurate within plus or minus 10 per cent on any component.

Effects of Pressure and Temperature on Liquid Condensation

The data on this particular well covered too limited a range to permit direct extrapolation over the entire range of temperature and pressure at which condensation could occur. It was possible, however, to interpret completely the results over the range encountered in separation practice in the light of experience obtained with the experimental unit in other fields producing materials of a similar nature.

TABLE 2.—*Hydrocarbon Analyses of Equilibrium Gas and Liquid Samples*
MOL PER CENT

	Operating Pressure, 500 Lb. per Sq. In. Gauge				Operating Pressure, 1000 Lb. per Sq. In. Gauge						Operating Pressure, 1500 Lb. per Sq. In. Gauge					
Temperature	−47°F.		−17°F.	80°F.	−42°F.		12°F.		77°F.		−15°F.		38°F.		81°F.	
Sample	Gas	Liquid	Gas	Gas	Gas	Liquid	Gas	Liquid	Gas	Liquid	Gas	Liquid	Gas	Liquid	Gas	Liquid
Component																
Methane	96.8	22.86	96.3		96.7	47.02	96.4	31.41	95.5	24.90	96.6	48.65	96.7	39.21	95.3	33.38
Ethane	2.54	7.62	2.59	98.8	2.49	8.90	2.41	5.12	2.63	3.95	1.90	3.80	2.04	5.35	2.71	4.65
Propane	0.49	8.85	0.70		0.37	7.51	0.76	6.75	0.85	3.60	0.80	6.32	0.73	4.44	0.93	3.57
Iso-butane	0.067	2.82	0.192	0.385	0.157	3.42	0.044	2.47	0.251	1.57	0.086	1.68	0.028	1.69	0.226	1.38
n-butane	0.064	6.40	0.143	0.298	0.143	3.83	0.121	5.13	0.303	2.70	0.235	2.57	0.080	2.55	0.352	2.00
Isopentane	0.021	3.49	0.052	0.184	0.051	2.46	0.096	3.67	0.148	2.55	0.115	2.38	0.118	2.12	0.161	2.00
n-pentane	0.003	3.46	0.011	0.078	0.020	1.86	0.036	1.74	0.059	1.61	0.064	0.96	0.071	1.60	0.063	1.17
Hexanes		7.31	0.019	0.179	0.030	3.91	0.067	6.60	0.148	6.57	0.133	4.25	0.134	5.28	0.185	4.95
Heptanes		8.06				4.90		8.59		7.43		5.70		6.08		6.18
Octanes		4.99				3.24		4.15		7.01		3.67		4.13		5.71
Nonanes		4.24				1.96		4.85		6.22		3.55		5.14		5.46
Heavier	0.008	19.90	0.007	0.037	0.013	10.99	0.022	19.52	0.071	31.89	0.060	16.47	0.083	22.41	0.091	29.55
Molecular weight		182				178		175		184		176		176		181
Density, grams per c.c. at 60°F.		0.8124				0.8094		0.8106		0.8119		0.8102		0.8099		0.8120

Curves are presented in Fig. 5 showing the effect of temperature on the amount of gross liquid condensed in the separator at various operating pressures, and in Fig. 6

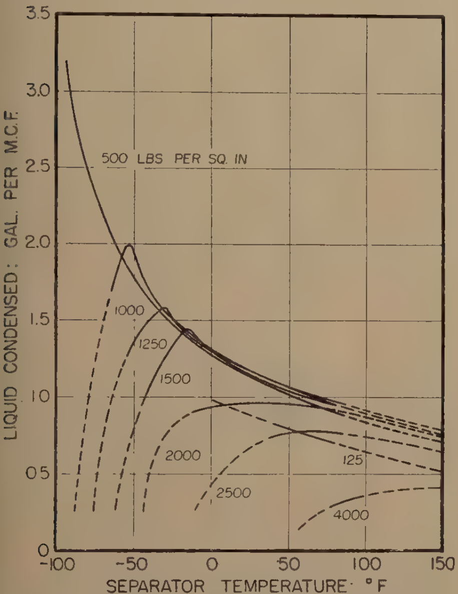


FIG. 5.—EFFECT OF SEPARATION TEMPERATURE ON GROSS LIQUID YIELD AT VARIOUS PRESSURES.

showing the effect of pressure on the amount of gross liquid condensed in the

TABLE 3.—*Results of A.S.T.M. Distillation of Condensate from Separator at 500 Pounds per Square Inch and Minus 49°F.*

Distillation, Per Cent Over	Temperature, Deg. F.	Results	
I.B.P.	98	Recovery, per cent	93.5
10	170	Residue, per cent	3.0
20	200	Loss, per cent	3.5
30	232	Gravity of sample, deg. A.P.I. at 60°F	57.7
40	276		
50	327		
60	389		
70	447		
80	504		
90	580		
End point	614		

separator at various temperatures, cross plotted from Fig. 5. The solid portions of these curves represent the range covered by the data, while the dotted portions represent extrapolations added for the purpose of clarifying the observed phenomena.

The most striking feature of these curves

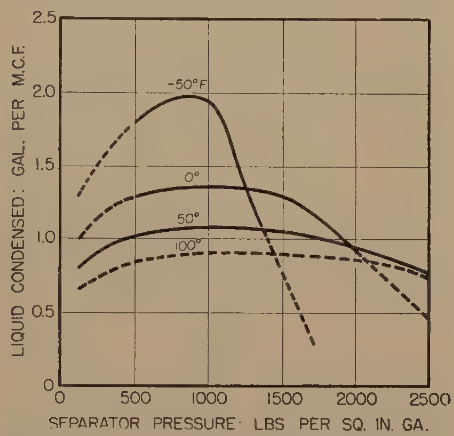


FIG. 6.—EFFECT OF SEPARATION PRESSURE ON GROSS LIQUID YIELD AT VARIOUS TEMPERATURES.

is their demonstration of the fact that in addition to the commonly observed pressure of maximum liquid yield for a fixed

TABLE 4.—*Calculated Composition of Reservoir Material*

Component	Mol Per Cent
Methane	94.11
Ethane	2.67
Propane	0.89
Isobutane	0.21
n-butane	0.34
Isopentane	0.20
n-pentane	0.10
Hexanes	0.29
Heavier	1.19
	100.00

temperature there exist also, at pressures of 1000 lb. per sq. in. and higher, temperatures of maximum liquid condensation. Below these optimum temperatures the amount of condensate decreases rapidly and finally vanishes with further temperature reduction, the material remaining entirely in the vapor phase at low enough temperatures. While this phenomenon was not unexpected and had been observed with this experimental unit in other fields, there seems to have been no other reported observation of it, and its existence appar-

ently has been overlooked because of a tendency to interpret the behavior of gas-distillate systems in terms of the phase diagrams of mixtures having higher critical

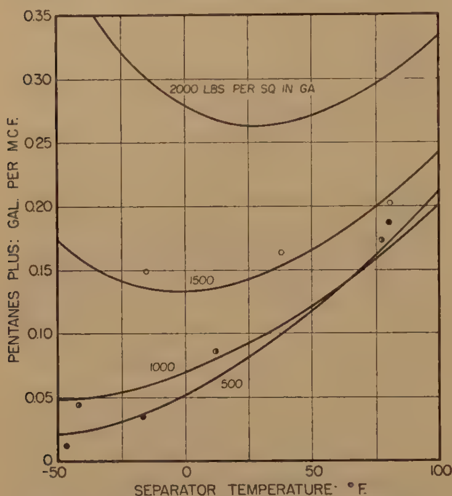


FIG. 7.—EFFECT OF SEPARATION TEMPERATURE ON PENTANES PLUS CONTENT OF RESIDUE GAS AT VARIOUS TEMPERATURES.

temperatures. These data indicate that the critical pressure of this particular reservoir material is probably below 1000 lb. per sq. in. and the critical temperature below −64°F. Thus substantially the entire two-phase region of this system is above the critical temperature and enclosed by a dew-point curve. The implications of this will be discussed later.

Correlation of Hydrocarbon Analyses and Calculation of Observed Phenomena

A major part of the investigation of which this paper presents a part was the development of correlations that would permit the use of a limited amount of experimental and analytical data on any particular system to calculate the complete phase behavior. Space here does not permit the presentation of the data acquired on all of the investigations made nor of the correlations developed. However, to present the results briefly, it has been found that the range over which analytical data may be extrapolated with satisfactory precision may be greatly extended by the use of the product of the equilibrium constant K, defined as the mol fraction of a component in the vapor divided by the mol fraction in the liquid at equilibrium, times the absolute pressure, correlated graphically as functions of temperature and pressure. It has been found experimentally that for many hydrocarbons plots of log KP vs. the absolute pressure and vs. the reciprocal of the absolute temperature yield substantially straight lines or smooth curves over a considerable range of pressure and temperature. This correlation is especially useful for interpolation between widely scattered data points. For many gas-distillate systems a few experimentally determined equilibrium analyses at the upper and lower temperature and pressure limits of the range in which the investigator is interested will suffice and the remainder can be filled in by calculation.

Effect of Separation Conditions on Composition of Residue Gas

In the design of plants for the recovery of distillate from natural gas, the composition of the residue gas rather than the amount of liquid condensed is the key to the extraction efficiency. Of particular importance is the content of pentanes and heavier hydrocarbons. In Figs. 7 and 8 are presented calculated pentanes plus content of the residue gas at various pressures and temperatures, expressed as gallons at 60°F. per M cu. ft. of residue gas corrected to 60°F. and atmospheric pressure. In Fig. 7, which shows the effect of temperature on the residue content at various pressures, the experimentally determined values are shown for comparison. In most cases the experimental values checked those calculated within 0.015 gal. per thousand. The increased gasoline content of the residue gas, reflecting the lower yield at excessively reduced temperatures shown in Fig. 5, is noticeable at 1500 and at 2000 lb. per

sq. in. It may be observed that the temperature for minimum loss for this particular gas decreases with reduced pressure, varying from approximately 30°F. at 2000

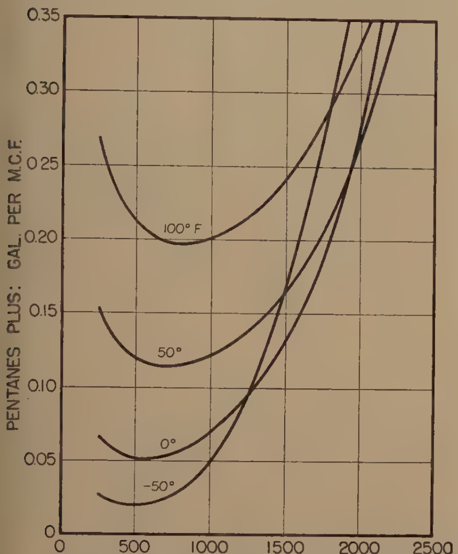


FIG. 8.—EFFECT OF SEPARATION PRESSURE ON PENTANES PLUS CONTENT OF RESIDUE GAS AT VARIOUS TEMPERATURES.

lb. per sq. in. to approximately −50°F. at 1000 lb. per sq. in. gauge.

The curves in Fig. 8, showing the effect of pressure on the pentanes plus content of the residue gas at a series of temperatures, illustrate clearly the well-known optimum pressure for maximum liquid yield or minimum loss. Particularly interesting is the fact that for this particular gas the optimum pressure increases with increasing temperature from about 500 lb. per sq. in. gauge at −50°F. to approximately 800 lb. per sq. in. gauge at +80°F. The increased loss in pentanes plus with increased pressure above the optimum is very pronounced for this gas.

Combined Effects of Pressure and Temperature—Phase Diagram

As mentioned earlier, the combined effects of pressure and temperature on the condensation phenomena are most readily portrayed by means of phase diagrams. An illustrative phase diagram for the reservoir gas is presented in Fig. 9, showing

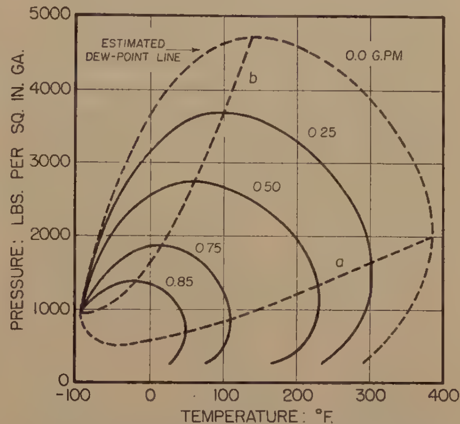


FIG. 9.—PHASE DIAGRAM SHOWING COMBINED EFFECTS OF PRESSURE AND TEMPERATURE ON YIELD OF PENTANES AND HEAVIER HYDROCARBONS.

the estimated positions of the critical point, the dew-point line, and lines of constant condensation of pentanes and heavier hydrocarbons. This diagram is by no means exact, but is believed to be qualitatively correct in all its essential features. The critical conditions were estimated by calculating the molal average critical temperature of the mixture, −93°F., and extrapolating the vapor-pressure curve of methane to this temperature to find the critical pressure of 935 lb. per sq. in. gauge. Since the reservoir material contained 94 per cent methane, it is believed that the true critical temperature and pressure cannot differ significantly from these values. The portion of the diagram outside of the range covered by the experimental data was arrived at by a combination of extrapolation and calculation.

The most important feature of this diagram is the fact that because of the low critical temperature and pressure almost the entire two-phase region is enclosed within a dew-point curve. Accordingly, it

is readily seen that at any temperature above −93°F. isothermal increase of the pressure from atmospheric will increase the condensation of pentanes and heavier up to some maximum value, whereupon continued pressure increase will lead to complete disappearance of the liquid. This phenomenon has been observed so frequently as to be accepted as characteristic of all gas-distillate systems. Equally clear from the diagram, however, is the fact that along any isobar above the critical pressure, decreasing the temperature from a high value will also increase the amount condensed of pentanes plus until it reaches a maximum, after which continued temperature reduction will result in decreased condensation and finally complete disappearance of the liquid phase. This latter phenomenon may or may not be characteristic of all gas-distillate systems. It is probable, however, that it is characteristic of many, particularly of those with low distillate content.

The loci of the optimum pressures are indicated in Fig. 9 by the dotted line labeled *a* and the loci of the optimum temperatures by the dotted line labeled *b*. Since these lines terminate at the critical point, their positions will be different for different mixtures. It is probable that within the range of compositions ordinarily encountered in gas-distillate mixtures, the richer the gas the higher will be the critical temperature and pressure and the higher the optimum pressure for a given temperature. The optimum temperature may be either higher or lower or may disappear, depending upon the exact position of the critical point.

Conclusions

An experimental separator has been operated, which attained temperatures low enough to permit the observation of optimum temperatures as well as optimum pressures for the separation of distillate from natural gas. The results indicated that most gas-distillate systems are probably characterized by low critical temperatures and pressures, from which it may be expected that most of them will exhibit optimum separation temperatures at certain pressures and optimum separation pressures at all temperatures normally encountered.

Also developed was an experimental and analytical technique that yields sufficiently accurate hydrocarbon analyses of lean gases to permit their use, with certain simple correlations, to calculate from a few experimental points the complete behavior of any particular gas-distillate mixture.

Acknowledgments

The authors gratefully acknowledge the assistance of the personnel of the Natural Gas Department of the Humble Oil and Refining Co. in the operation of the experimental unit and in the analysis of the hydrocarbon samples, and of Dr. C. R. Hocott in the correlation of the results.

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DISCUSSION

J. SWEARINGEN,* Austin, Texas.—The discovery of an optimum separation temperature probably was not a surprise to the authors of this paper. The large deviations from the gas laws for methane at low temperatures approaching the critical indicates increasing intermolecular forces with fall in temperature and therefore an increasing tendency to dissolve the liquid hydrocarbons. It seems reasonable that this effect might predominate over the reduction of fugacity of the liquid due to the fall in temperature, to produce a maximum in the yield-temperature curve.

An important application of this work that has not been elaborated on is its clarification of the shrinkage-value variation. In determining economical separation conditions, uncertainty often originates in inaccurate shrinkage values (ratios of "net" to "gross" yields). Correlated shrinkage values over a wide range can be calculated from the data reported in this paper to show clearly the normal shape of these shrinkage curves.

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Chapter III. Petroleum Economics

World Production of Petroleum Substitutes

By V. R. Garfias* and R. V. Whetsel,* Members A.I.M.E.

(New York Meeting, February 1941)

The present study is intended as a preliminary statistical survey of the world's production of petroleum substitutes. The information presented is admittedly deficient. It is believed, however, that the increasing importance of these substitutes, particularly with Europe at war, justifies its presentation at this time, if for no other reason than to encourage enlightened pertinent discussion.

The world's production in 1939 of petroleum substitutes—of which approximately 97 per cent are direct substitutes for motor fuels—is tentatively estimated at 108,000,000 bbl., or equivalent to the combined output of crude oil in 1939 of Rumania, Mexico and Colombia. With few exceptions, these figures of production represent also actual figures of consumption. The United States, owing mainly to its output of natural gasoline, leads all countries in the production of these products, with about 53 per cent of the total.

In European countries, particularly Germany, the imminence of war in 1939 forced an increase in production and improvement of methods of manufacturing motor fuels, largely from coal, with the result that this country produced in that year over 20,000,000 bbl. of substitutes. Since the beginning of hostilities, substitutes have offered more and more the means of meeting the unfavorable balance between supply and demand in European countries; the increase in production of these products being at least in part offset by the systematic bombing of synthetic plants and oil storage.

Table 1.—*Petroleum Substitutes and Their Source Material*

From Natural Gas	From Coal	From Oil Shales	From Molasses, Potatoes, etc.	From Wood
Methane Liquid gas Natural gasoline Methyl alcohol	Liquid gas Manufactured gas Gasoline Benzol Lubricants Etc.	Shale oil Gasoline Gas oil Lubricants Etc.	Ethyl alcohol	Producer gas Methyl alcohol

The source materials and the resulting substitutes are listed in Table 1. The following are the approximate gross heat equivalents of some substitutes to barrels of gasoline:

	Equivalent, Bbl. Gasoline 60° A.P.I.
One barrel:	
Benzol	1.07
Natural gasoline[a]	0.941
Butane	0.823
Propane	0.730
Ethyl alcohol	0.671
Methyl alcohol	0.507
One M cu. ft.:	
Natural gas[b]	0.219
Methane gas[c]	0.196
Manufactured gas[d]	0.103
Producer gas[e]	0.019

[a] Assuming 75° A.P.I. natural gasoline.
[b] Assuming 1150 B.t.u. per cu. ft.
[c] Assuming 1009 B.t.u. per cu. ft.
[d] Assuming 537 B.t.u. per cu. ft.
[e] Assuming 100 B.t.u. per cu. ft.

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* Cities Service Co., New York, N. Y.

Petroleum Substitutes from Natural Gas

The most important petroleum substitute, natural gasoline, is a mixture of liquid hydrocarbons extracted from "wet" natural gas associated or not with petroleum. It is chiefly used for blending with refinery products in the manufacture of high-quality motor fuels. There is a question as to whether some natural gasoline should be considered a petroleum product rather than a substitute.

The following approximate composition of natural gas illustrates some of the products that can be derived from it:

Constituents		Percentages	
		Dry Gas	Wet Gas
Methane	illuminating gas	98.0	91.4
Ethane		1.0	3.1
Propane	liquefied, then used as gas		1.9
Butane			1.1
Pentane	natural gasoline		0.4
Hexane			1.5
Miscellaneous		1.0	0.6
		100.0	100.0

The United States produces close to 80 per cent of the total yield of natural gasoline, Canada ranking second.

Propane and butane, hydrocarbons too light to be converted into natural gasoline, may be liquefied, transported as liquids and utilized as gases, as fuel in gas ranges, for motor fuel, and other uses. Liquid gas is also obtained as a by-product in the manufacture of synthetic gasoline from coal. The United States produces close to 5,000,000 bbl. of liquid gas, the greater part of which may be classed as potential substitute for motor fuel. Methane obtained from wells in Italy is used as fuel in motor vehicles.

Petroleum Substitutes from Coal

Chief among the petroleum substitutes from coal are gasoline and benzol. The latter is usually blended with lower-grade refinery gasoline, and sometimes with alcohol. Kerosene, Diesel and fuel oils, and to a lesser extent lubricants, are also commercially produced from coal.

The most important methods of producing these petroleum substitutes from coal are:

1. High-temperature carbonization, in which coal is heated in coking ovens and benzol is recovered, is the oldest and most important.

2. Low-temperature carbonization, in which tar oils are extracted at low temperatures and later pressure-cracked to obtain motor fuel and other products.

3. Hydrogenation, in which in order to convert coal into liquid hydrocarbon, hydrogen is added, as the ratio of hydrogen to carbon is much lower in coal than in petroleum. It is claimed that hydrogenation is the most efficient process but the added expense necessitates development on a large scale for profitable operation.

Manufactured gas from coal is utilized as a motor fuel in Germany, England and Italy. The gas is compressed into lightweight cylinders at a pressure of about 4000 lb. per sq. in., and is carried on automobiles and trucks. Its performance in the motors as a substitute for gasoline is reported to be satisfactory. Producer gas from wood is also now being used in Europe as motor fuel.

The world's production in 1939 of petroleum substitutes from coal is estimated at about 28,730,000 bbl., the German output representing close to 60 per cent of the total.

Petroleum Substitutes from Oil Shales

Shale oil is obtained commercially by grinding oil shales and retorting them in a manner similar to low-temperature carbonization of coal. The Australian shales yield about 100 gal., the Estonian 50 gal., the Scottish and French 25 and the Man-

TABLE 2.—*World Production of Petroleum Substitutes*

1938

Country	Motor Fuel, Bbl. Gasoline: Natural	Gasoline: From Coal	Gasoline: From Shale Oil	Benzol	Alcohol	Liquid Gas	Methane[a]	Manufactured Gas[a]	Producer Gas[a]	Total Motor Fuel	Shale Oil and Miscellaneous Products, Bbl.	Total U. S. Barrels
United States	51,347,000			1,764,000		3,800,000[b]				56,911,000		56,911,000
Germany		10,200,000		3,800,000	1,700,000	1,300,000		110,000	40,000	17,150,000	1,200,000	18,350,000
United Kingdom		3,003,000	224,000	1,800,000	200,000			20,000	20,000	5,267,000	500,000	5,767,000
France		900,000	12,000	629,000	1,600,000			220,000	80,000	3,441,000	70,000	3,511,000
Japan		1,200,000			2,100,000					3,300,000		3,300,000
Canada	3,000,000									3,000,000		3,000,000
Netherlands East Indies	2,000,000									2,000,000		2,000,000
Estonia			200,000							200,000	1,200,000	1,400,000
Russia	1,000,000		38,000							1,038,000	165,000	1,203,000
Peru	1,200,000									1,200,000		1,200,000
Mexico	1,000,000									1,000,000		1,000,000
Iran	1,000,000									1,000,000		1,000,000
Venezuela	900,000									900,000		900,000
Rumania	700,000									700,000		700,000
Colombia	600,000									600,000		600,000
Italy	50,000				360,000		31,000	100,000	40,000	581,000		581,000
Australia			1,200		494,000					495,200	4,800	500,000
Argentina	400,000									400,000		400,000
Belgium				290,000						290,000		290,000
Philippine Islands					280,000					280,000		280,000
Trinidad	200,000									200,000		200,000
New Zealand					200,000					200,000		200,000
British Borneo	150,000									150,000		150,000
Egypt	150,000									150,000		150,000
British India	140,000									140,000		140,000
Sweden				4,000	104,000				15,000	123,000		123,000
Hungary					65,000					65,000		65,000
Ecuador	60,000									60,000		60,000
Poland					53,000					53,000		53,000
Lithuania					50,000					50,000		50,000
Spain			9,000							9,000	39,000	48,000
Chile					13,000					13,000		13,000
	63,897,000	15,303,000	484,200	8,287,000	7,219,000	5,100,000	31,000	450,000	195,000	100,966,200	3,178,800	104,145,000

[a] Used as gases for transportation motor fuels.
[b] Largely propane-butane.

TABLE 2.—(*Continued*)

1939

Country	Motor Fuel, Bbl.										Shale Oil and Miscellaneous Products, Bbl.	Total U. S. Barrels
	Gasoline			Benzol	Alcohol	Liquid Gas	Methane[a]	Manufactured Gas[a]	Producer Gas[a]	Total Motor Fuel		
	Natural	From Coal	From Shale Oil									
United States	49,896,000			2,440,000		5,000,000[b]				57,336,000		57,336,000
Germany		11,500,000		4,300,000	1,300,000	1,400,000		120,000	40,000	18,660,000	1,500,000	20,160,000
United Kingdom		3,200,000	230,000	2,000,000	250,000			25,000	25,000	5,730,000	600,000	6,330,000
Japan		1,600,000			2,396,000					3,996,000		3,996,000
France		900,000	13,000	600,000	1,600,000			230,000	80,000	3,423,000	75,000	3,498,000
Canada	3,000,000									3,000,000		3,000,000
Netherlands East Indies	2,000,000									2,000,000		2,000,000
Estonia			220,000							220,000	1,080,000	1,300,000
Russia	1,000,000		40,000							1,040,000	175,000	1,215,000
Peru	1,100,000									1,100,000		1,100,000
Mexico	1,000,000									1,000,000		1,000,000
Iran	1,000,000									1,000,000		1,000,000
Venezuela	1,000,000									1,000,000		1,000,000
Rumania	800,000									800,000		800,000
Colombia	700,000									700,000		700,000
Italy	60,000				350,000		71,000	110,000	40,000	631,000		631,000
Australia			1,200		450,000					451,200	5,000	456,200
Argentina	450,000									450,000		450,000
Belgium				300,000						300,000		300,000
Philippine Islands					300,000					300,000		300,000
Sweden				5,000	250,000				20,000	275,000		275,000
Trinidad	250,000									250,000		250,000
New Zealand					180,000					180,000		180,000
British Borneo	160,000									160,000		160,000
Egypt	160,000									160,000		160,000
British India	150,000									150,000		150,000
Poland					100,000					100,000		100,000
Ecuador	80,000									80,000		80,000
Hungary					80,000					80,000		80,000
Spain			9,500							9,500	41,000	50,500
Lithuania					50,000					50,000		50,000
Chile					13,000					13,000		13,000
	62,806,000	17,200,000	513,700	9,645,000	7,319,000	6,400,000	71,000	485,000	205,000	104,644,700	3,476,000	108,120,700

[a] Used as gases for transportation motor fuels.
[b] Largely propane-butane.

churian shales about 14 gal. of shale oil per ton. Shale oil has a gravity of about 29°A.P.I. and is refined by distillation and treatment with sulphuric acid and caustic soda; the products are all those derived from similar crude oils. The world's production in 1939 of petroleum substitutes from oil shales aggregated about 2,490,000 bbl., Estonia being the leading producer, with an output of 1,300,000 barrels.

Alcohol

Synthetic alcohol, particularly as methanol, has come into extensive use as a petroleum substitute for blending with motor fuel in European countries, in some of which it has been mandatory to add 10 to 20 per cent of alcohol to commercial gasoline.

Ethyl alcohol is manufactured largely from potatoes, sugar beets, molasses, rye and other vegetable substances. The approximate yield in gallons of 99.5 per cent ethyl alcohol per ton of the base materials is 84 from corn, 22.9 from potatoes, 34.2 from sweet potatoes, 22.1 from sugar beets, 78.8 from rye and 70.4 from blackstrap molasses. The world's production in 1939 of alcohol used as motor fuel was approximately 7,320,000 bbl. The United Kingdom, with close to 2,400,000 bbl., was the leading producer.

World Consumption of Petroleum and Its Substitutes in 1940

By V. R. Garfias,* and R. V. Whetsel,* Members, and J. W. Ristori,* Associate Member A.I.M.E.

(New York Meeting, February 1941)

World consumption of petroleum and its substitutes in 1940, which, except for the United States, *does not include consumption for military purposes even in peacetime,* is estimated at 2,006,000,000 bbl., or approximately 21,000,000 bbl. less than in 1939. As consumption figures for belligerent countries and those affected by the war are unavailable, in order to arrive at a gross approximation the assumption has been made that the rate of civil consumption in these countries has declined 80 per cent since the German occupation or the effect of the war made itself felt.

In 1940 the total consumption in the United States increased 94,000,000 bbl. over the previous year, while the civil consumption in the countries directly affected by the war—some of them occupied during the last half of the year—decreased 126,000,000 bbl. In the rest of the world consumption increased 11,000,000 bbl., resulting in an over-all decrease in world civil consumption grossly estimated at 21,000,000 barrels.

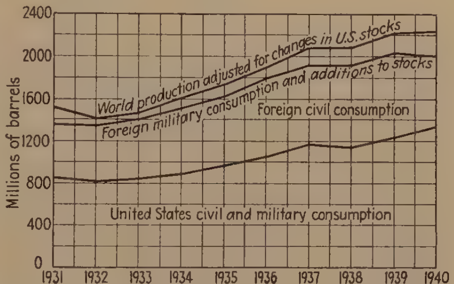

Fig. 1.—World production and consumption of petroleum and its substitutes.

Although no reliable information is available regarding military consumption in foreign countries before or during the war, military consumption and/or addition to stocks in foreign countries in 1940, as

Manuscript received at the office of the Institute Feb. 20, 1941.
* Cities Service Co., New York, N. Y.

Table 1.—*World Petroleum Balance Sheet*
Thousands of Barrels

Year	Production of Petroleum and Its Substitutes	Civil Consumption of Petroleum and Its Substitutes[a]	Excess Production over Consumption			United States		Foreign Military Consumption and Additions to Stocks
			United States	Foreign	World Total	Excess Exports over Imports	To Stocks	
1932	1,362,039	1,348,407	R13,011	26,643	13,632	28,781	R41,792	55,424
1933	1,467,128	1,406,923	67,427	R7,222	60,205	60,254	7,173	53,032
1934	1,562,834	1,507,599	26,164	29,071	55,235	64,013	R37,849	93,084
1935	1,702,793	1,614,475	53,027	35,291	88,318	75,474	R22,447	110,765
1936	1,864,997	1,795,560	52,209	17,228	69,437	74,890	R22,681	92,118
1937	2,121,337	1,914,856	161,445	45,036	206,481	115,677	45,768	160,713
1938	2,062,090	1,917,927	124,047	20,116	144,163	139,420	R 9,077	153,240
1939	2,182,883	2,026,557	86,222	70,104	156,326	134,811	R30,082	186,408
1940[b]	2,265,710[b]	2,005,885[b]	88,100[b]	171,825[b]	259,925[b]	51,000[b]	38,700[b]	221,225[b]

[a] Includes U. S. military consumption.
[b] 1940 figures largely conjectural.

TABLE 2.—*World Consumption of Petroleum and Its Substitutes*
THOUSANDS OF BARRELS

Country	1938*	1939						1940 (Estimated)				
								Months		Consumption		
	Total	Motor Fuel	Kero-sene	Gas and Fuel Oil	Lubri-cants	Misc.	Total	Before German Control[c]	Under German Control[d]	Before German Control[c]	Under German Control[d]	Total[e]
United States	1,140,923[a]	557,009	64,003	458,461	23,713	132,890	1,236,076[b]					1,330,000
Russia	164,500	28,000	44,000	67,000	9,600	22,000	170,600					180,000[e]
United Kingdom	90,300	44,000	7,000	29,900	2,900	4,400	88,200	6	6			50,000
Germany	56,700	24,200	800	18,100	3,800	7,100	54,000					35,000[e]
Canada	45,900	24,300	1,000	18,400	1,300	4,200	49,200					50,000
France	49,100	22,000	1,400	15,000	1,800	4,000	44,200	5½	6½	17,000	4,500[e]	21,500[e]
Argentina	29,500	8,000	1,900	18,600	550	1,900	30,950					33,000
Japan	25,000	8,000	1,500	12,000	1,800	2.100	25,400					26,000[e]
Italy	20,500	5,700	1,000	12,200	1,000	1,900	21,800	5⅓	6⅔	8,000	2,500[e]	10,500[e]
Netherlands West Indies	20,650	250	50	15,500	50	4,000	19,850					20,000
Mexico	18,000	3,500	800	12,700	200	1,400	18,600					19,000
Australia	16,250	10,500	1,200	3,100	480	1,000	16,280					16,000
British India (ex. Burma)	15,450	3,100	6,100	4,600	1,000	900	15,700					16,200
Rumania	12,780	1,300	1,500	10,000	200	1,400	14,400	8	4			14,000[e]
Netherlands	10,950	4,100	2,000	4,300	600	800	11,800	5½	6½	4,000	1,300[e]	5,300[e]
Netherlands East Indies	11,350	1,500	2,000	6,200	250	1,500	11,450					11,500
Iran	10,600	650	1,300	6,000	450	2,700	11,100					11,500
Sweden	10,050	5,100	1,000	3,700	450	700	10,950	4½	7½	3,000	1,500[e]	4,500[e]
Union of South Africa	8,270	5,800	650	3,000	350	500	10,300					10,500
Venezuela	8,925	1,150	40	8,000	40	300	9,530					9,000
Brazil	8,820	3,250	800	4,800	300	150	9,300					9,500
Denmark	6,680	2,900	850	2,650	230	300	6,930	4½	7½	2,000	900[e]	2,900[e]
Belgium	6,395	4,000	170	1,600	480	500	6,750	5½	6½	2,500	800[e]	3,300[e]
Egypt	5,650	850	2,600	2,200	250	400	6,300					6,000
French West Africa	5,390	400	100	5,200	50	20	5,770	5½	6½	2,500	700[e]	3,200[e]
Cuba	4,800	800	100	4,300	60	140	5,400					5,600
Chile	5,030	750	70	4,300	80	60	5,260					5,400
Spain	4,650	3,000	150	1,800	170	140	5,260	?	?			4,000[e]
Norway	4,580	2,000	350	2,600	100	200	5,250	4½	7½	1,500	700[e]	2,200[e]
New Zealand	5,370	3,300	200	1,300	120	300	5,220					5,300
Aden	4,937	20	15	5,000	2	100	5,137					5,000
Trinidad	4,720	140	80	4,400	40	450	5,110					5,000
British Malay	4,250	1,100	300	3,200	100	200	4,900					5,000
China	4,600	800	1,700	1,400	200	250	4,350					4,000
Philippine Islands	3,700	1,100	400	2,500	110	140	4,250					4,400
Iraq	3,840	350	250	2,700	60	800	4,160	6	6	2,100	1,100[e]	3,200
Hawaiian Islands	4,000	1,200	200	2,500	140	100	4,140					4,300
Colombia	2,975	930	135	2,150	27	135	3,377					3,500
Switzerland	3,250	1,600	170	1,200	150	190	3,310	5½	6½	1,500	400[e]	1,900
Poland	3,050	Included in Germany and Russia										
Uruguay	3,030	800	280	2,100	40	50	3,270					3,300
Ceylon	3,380	370	220	2,500	20	100	3,210					3,000
Panama Canal Zone	3,000	130	30	2,900	30	40	3,130					3,200
Greece	2,650	610	190	1,900	80	120	2,900	10	2			3,000[e]
Finland	2,100	1,450	550	140	140	160	2,440	3	9	500	400[e]	900[e]
Irish Free State	2,350	1,200	550	350	80	250	2,430					2,100
Czechoslovakia	2,220		Included in Germany									
Peru	2,570	450	200	1,450	30	250	2,380					2,300
Hungary	1,930	820	630	680	120	120	2,370	?	?			1,800[e]
Algeria	1,855	1,000	300	480	90	120	1,990	5½	6½	900	200[e]	1,100[e]
Puerto Rico	1,800	550	90	1,150	40	50	1,880					1,900
Palestine	1,600	400	450	690	30	200	1,770					1,700
Jamaica	1,620	230	60	1,400	10	40	1,740					1,700
Burma	1,550	200	50	1,000	50	300	1,600					1,600
Portugal	1,515	600	380	450	80	50	1,560					1,500
French Morocco	1,420	900	100	340	50	150	1,540	5½	6½	700	200[e]	900[e]
Hong Kong	1,240	120	90	1,100	40	30	1,380					1,300
Turkey	1,280	450	350	450	60	20	1,330					1,200
Yugoslavia	1,090	350	210	340	70	120	1,090					1,000[e]
Kenya and Uganda incl. Zanzibar	980	340	100	530	25	10	1,005					1,000
Miscellaneous	16,362	6,407	3,085	5,406	684	1,400	16,982					14,185
Total	1,917,927	804,026	155,798	807,917	54,971	203,845	2,026,557					2,005,885[c]

* Detailed figures for former years appear in earlier volumes of the TRANSACTIONS.
[a] Includes 3,800.000 bbl. of propane-butane.
[b] Includes 5,000,000 bbl. of propane-butane.
[c] Or before war affected consumption.
[d] Or after war affected consumption.
[e] Highly conjectural.

TABLE 3.—*Consumption of Petroleum and Its Substitutes in "Miscellaneous" Countries*
THOUSANDS OF BARRELS

Country	1938	1939						1940 (Estimated)				Total[d]
								Months		Consumption		
	Total	Motor Fuel	Kerosene	Gas and Fuel Oil	Lubricants	Misc.	Total	Before German Control[a]	Under German Control[b]	Before German Control[a]	Under German Control[b]	
Indo China	900	310	300	170	35	118	933					800
Tunis	762	400	200	250	40	8	898	5½	6½	400	100[d]	500[d]
Italian E. Africa	931	400	8	65	34	350	857	5⅓	6⅔	250	100[d]	350[d]
Honduras	820	390	95	275	30	45	835					800
Bulgaria	700	235	250	200	50	70	805	6	6	400	90[d]	490[d]
Sarawak	814	14	34	730	4.5	14	796.5					800
Syria	732	280	250	130	27	40	727	5½	6½	300	80[d]	380[d]
Guatemala	610	150	50	430	12	30	672					680
Siam	705	150	150	200	30	60	590					500
Gold Coast	550	220	80	175	45	35	555					550
Libya	397	145	50	250	20	50	515	5⅓	6⅔	350	60[d]	410[d]
Bolivia	451	134	28	245	30	30	467					470
Latvia	420	160	230	19	15	34	458	6½	5½[c]	250	125[d]	375[d]
Southern Rhodesia	350	230	21	90	22	55	418					430
Ecuador	392	165	45	55	15	130	410					410
Malta	358	85	140	130	11	5	371					250[d]
Estonia	350	140	70	85	31	40	366	6½	5½[c]	180	100[d]	280[d]
Dominican Republic	354.9	110	35	200	10	5.5	360.5					365
Lithuania	330	210	43	68	25	1	347	6½	5½[c]	170	80[d]	250[d]
Panama	261	210	45	40	8	10	313					320
Belgian Congo	268	170	21	32	25	20	268					270
Nigeria	313.3	139.7	57	29.6	16.5	0.3	243.1					245
Sierra Leone	239.5	12	13.5	215	1.5	1	243					245
Nicaragua	188	90	30	80	5	9	214					220
Iceland	203	115	30	59	5.9	0.4	210.3					210
Tanganyika	195	90	46	65	2	0.3	203.3					200
Cyprus	189	50	26	114	5.5	0.5	196	5⅓	6⅔	80	20[d]	100[d]
El Salvador	170	57	20	84	4.2	5	170.2					170
Newfoundland	160	118	23	11	11	2.5	165.5					165
Portuguese E. Africa	147	65	25	30	13	22	155					150
Madagascar	144	80	32	30	1	1	144					140
British Guiana	132	31	13.4	84	5.6	0.3	134.3					130
Bermuda	153	17	18	93	0.6	0.5	129.1					130
Barbados	116	52	14	50	3	2	121					120
Haiti	110	63	23	29	3	2	120					120
Martinique	107.8	75	10	24	3	3	115					110
Fiji Islands	103	44	9	49	3.7	0.2	105.9					100
Others	2,235	1,000	550	520	80	200	2,350					1,950
Total	16,361.6	6,406.7	3,084.9	5,405.6	684	1,400.5	16,981.7					14,185[d]

[a] Or before war affected consumption.
[b] Or after war affected consumption.
[c] Under Russian control.
[d] Highly conjectural.

shown in Table 1, are roughly estimated at 221,000,000 bbl. or about 35,000,000 bbl. more than in 1939. The peacetime consumption for military purposes of these countries has been previously roughly estimated at 47,500,000 barrels.

TABLE 4.—*World Production of Petroleum and Its Substitutes*
THOUSANDS OF BARRELS

Country	1939			1940 (Estimated)		
	Crude Oil	Petroleum Substitutes	Total	Crude Oil	Petroleum Substitutes	Total
United States	1,264,962	57,336	1,322,298	1,360,000	58,100	1,418,100
Russia	218,000	1,300	219,300	223,000[a]	1,300	224,300[a]
Venezuela	206,000	1,000	207,000	186,000	1,000	187,000
Iran	78,200	1,000	79,200	80,000	1,000	81,000
Netherlands E. I.	61,600	2,000	63,600	60,800	2,000	62,800
Rumania	46,000	800	46,800	44,000	800	44,800
Mexico	42,800	1,000	43,800	40,000	1,000	41,000
Iraq	30,800		30,800	27,000		27,000
Colombia	22,000	700	22,700	26,000	800	26,800
Germany	6,700	20,175	26,875	6,700	20,000[a]	26,700[a]
Trinidad	19,300	250	19,550	20,000	300	20,300
Argentina	18,500	450	18,950	20,000	500	20,500
Peru	13,500	1,100	14,600	13,500	1,100	14,600
Burma	7,400	150	7,550	6,800	150	6,950
Canada	4,900	3,000	7,900	5,300	3,300	8,600
British Borneo	7,100	160	7,260	7,100	160	7,260
Bahrein Island	7,600		7,600	6,300		6,300
Japan	3,700	3,996	7,696	3,700	4,500[a]	8,200[a]
United Kingdom		6,330	6,330		7,000[a]	7,000
Egypt	4,400	160	4,560	5,200	200	5,400
France	500	3,498	3,998	500	3,600[a]	4,100[a]
Saudi Arabia	3,900		3,900	5,400		5,400
Ecuador	2,300	80	2,380	2,500	100	2,600
British India	2,200		2,200	2,200		2,200
Estonia		1,300	1,300		1,300[a]	1,300[a]
Hungary	1,100	80	1,180	1,800	100[a]	1,900[a]
Albania	934		934	1,000		1,000
Miscellaneous	366	2,256	2,622	300	2,300	2,600
Total	2,074,762	108,121	2,182,883	2,156,100	110,610[a]	2,265,710[a]

[a] Highly conjectural.

Chapter IV. Production

Introduction

By James Terry Duce,* Member A.I.M.E.

The symposium on production for the year 1940 contains few papers on the foreign situation. It is probable that the foreign part of next year's symposium will be even shorter. This is due to rigid censorship in various countries, as the question of the volume of petroleum supplies has become one of great strategic importance. This is even more true than in the last war, owing to greater mechanization of armies.

It has always been the policy of officers in charge of the symposium to refrain from publishing information that might possibly injure national or private interests. At the close of the war we hope again to publish full and accurate records of production abroad.

Excerpts from Circular to Authors

In order to facilitate interpretation of the data in this chapter, we print the following excerpts from the Circular to Authors.

The field is the unit in this tabulation. In cases of fields extending across State boundaries, such as Rodessa, it is suggested that each State author treat the section of the field in his State as a unit, and by a footnote indicate that the field extends into an adjacent State.

Each space in Table 1 may represent one of four possibilities; either it is not applicable to the particular field, or the proper entry is not determinable, or the proper entry may be determinable but is not determinable from data available to the author, or the proper entry is determinable. When spaces are not applicable, leave blank; in spaces where the proper entries are determinable but not determinable from data available to the author, please insert y; in spaces where the proper entries are determinable by the author, make such entries. y implies a hope that in some future year a definite figure will be available.

The entry of a zero is a positive declaration, and an important declaration where it is in order.

Inability to determine precisely the correct entry for a particular space should not lead the author to insert merely y. Contributions of great value may be made by the author in many cases where entries are not subject to precise determination. In such cases the author should use his good judgment and make the best entry possible under the circumstances. For many spaces the correct entries represent the opinion of the author (for example, "Area Proved") and in such cases the entry need not be hedged to such extent as when the quantities are definite yet can be ascertained only approximately by the author.

In cases under definite headings but where figures are only approximate, the author may use x.

It is thought that the nearest whole numbers are sufficiently accurate for our purposes except as to percentage of sulphur in oil. If an author desires to report any other figures to tenths, he may do so.

The quantity of gas produced should include, where possible, gas sold or otherwise marketed, and gas blown into the air, burned as flares or otherwise wasted. Segregation of these figures would be interesting if the authors can make such segregation. In any event, the figures should represent as nearly as possible the total quantity of gas removed from the reservoir.

Under the columns on "Depth," the average depth to the top of the productive zones and to the bottom of the productive wells, when

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subtracted, should give the approximate thickness of the productive zone. For fields where this is not true because of unusually high dip or for some other reasons, it is suggested that the authors indicate in their text the approximate average thickness of the productive zone.

The net thickness of the producing formation should be the thickness of the producing zone, less the estimated amount to cover the portions of the zone that do not yield oil, such as dense shales, etc. It is recognized that for some fields the authors can only make rough guesses; in such cases, they should enter either *x* or *y*, whichever is appropriate, and production per acre-foot will have to be treated in a similar manner. Average production per acre-foot can be calculated by those interested from the figures given.

In classifying wells as to producing methods, enter all wells that are not "flowing" in the column headed "Artificial Lift." If desirable, add footnotes to indicate whether the lift is "pumping," "gas lift" or "air lift."

It is recognized that for many fields it would be very difficult to determine accurately the quantity of each gravity of oil produced. However, the approximate weighted average gravity, which will be representative of the total production can be determined sufficiently accurately to constitute significant information.

Footnotes to Column Headings—Table 1

[a] All fields to be listed alphabetically for the district; or alphabetically by counties in alphabetical order.

[b] Areas where both oil and gas are produced, unless gas is marketed outside the field, are included in column headed "Oil." Manufacture of casinghead gasoline and carbon black is interpreted as outside marketing of gas.

[c] Wells producing both oil and gas are classified as "Producing Oil." Gas wells are those producing gas, but include those producing wet gas, from which casinghead gasoline may be produced.

[d] State by letters, as indicated, type of operation: PM, pressure maintenance from early life of field; RP, field repressuring in its later life; SR, repressuring operations of secondary recovery type.

[e] Cam, Cambrian; Ord, Ordovician; Sil, Silurian; Dev, Devonian; Mis, Mississippian; MisL, Lower Mississippian; MisU, Upper Mississippian; Pen, Pennsylvanian; Per, Permian; Tri, Triassic; Jur, Jurassic; CreL, Lower Cretaceous; CreU, Upper Cretaceous; Eoc, Eocene; Olig, Oligocene; Mio, Miocene; Pli, Pliocene.

[f] S, sandstone; H, shale; L, limestone; OL, oōlitic limestone; LS, limestone, sandy; C, chalk; A, anhydrite; D, dolomite; Da, arkosic dolomite; Gw, granite wash; P, serpentine.

[g] Figures are entered only for fields where the reservoir rock is of pore type. Figures represent ratio of pore space to total volume of net reservoir rock expressed in per cent. "Por" indicates that the reservoir rock is of pore type but said ratio is not known by the author. "Cav" indicates that the reservoir rock is of cavernous type; "Fis," fissure type.

[h] A, anticline; AF, anticline with faulting as important feature; Af, anticline with faulting as minor feature; AM, accumulation due to both anticlinal and monoclinal structure; H, strata are horizontal or near horizontal; MF, monocline-fault; MU, monocline-unconformity; ML, monocline-lens; MC, monocline with accumulation due to change in character of stratum; MI, monocline with accumulation against igneous barrier; MUP, monocline with accumulation due to sealing at outcrop by asphalt; D,[f] dome; Ds, salt dome; T, terrace; TF, terrace with faulting as important feature; N, nose; S, syncline.

Oil and Gas Development in South Arkansas in 1940

By Warren B. Weeks,* Member A.I.M.E.

The year 1940 saw an increase of 20 per cent in oil production over the previous year—compared with a 16 per cent increase the previous year. In all, 25,790,380 bbl. were produced, an increase of 4,414,150 bbl. over 1939 and the largest production figure for south Arkansas since 1928.

The older settled production continued to decline. Magnolia accounted for most of the increase, with aid from the other recent deep fields. During the year, 169 wells were drilled, 79 fewer than in the previous year. Of 131 wells drilled in proven fields, 18 were dry. Three of the 38 wildcats were pool openers. The drilling depth record was increased from 9028 to 9550 feet.

Trend of Prospecting

For the first time since 1936, the search for oil in the deep Smackover limestone slackened perceptibly; 9 dry wildcats ended in Smackover, 2 in the underlying Eagle Mills; 7 penetrated Paleozoic beds, while 9 ended in Hosston, 2 in Glen Rose, 2 in Paluxy and 4 in Gulf.

Geology

The wells listed in Table 2 either resulted in the discovery of new oil pools or, because of their depth or location, afforded important stratigraphic or structural information. Fig. 1 is a general columnar and stratigraphic section showing the relationship of the strata within the Comanche series. The nomenclature shown was accepted by the Shreveport Geological Society. It was subsequently published by Imlay,[1] who indicated probable correlations with other areas and presented evidence for the possible Jurassic age of the underlying Cotton Valley and Smackover formations.

New Fields

Fouke.—On June 10, 1940, the Louark Producing Co. completed its No. 1 Sturgis, sec. 1, T. 17 S., R. 27 W., in central Miller County, producing between 3583 and 3607 ft. in the upper part of the Paluxy formation. The well flowed 100 bbl. of 31.4° gravity oil per day through 3/16-in. tubing choke. This discovery resulted from seismograph work. Six other wells were drilled in the area, none of which found production in the original sand. One of these wells is producing from a sand 50 ft. deeper in the section. The others were abandoned. No further development is in prospect. Production is from lenticular sands of the upper Paluxy; 45,556 bbl. had been produced by the end of 1940. There is structural closure against a fault to the northwest.

McKamie.—The Atlantic Refining Company's No. 1 Bodcaw Lumber Co., sec. 29, T. 17 S., R. 23 W., eastern central Lafayette County, was completed June 8, 1940, as the eighth and farthest west of the Smackover (Reynolds oölite) limestone pools. The well flowed 10 bbl. an hour of 58.6° gravity distillate through an 11/64-in. tubing choke, with a gas-oil ratio of 8400:1.

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* District Geologist, Phillips Petroleum Co., Shreveport, La.

[1] R. W. Imlay: Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities. Arkansas Geol. Survey *Inf. Circ.* 12. Little Rock, 1940.

Producing oölite was encountered from 9100 to 9206 ft. Two other wells were completed by the end of 1940 and the area had produced 76,147 bbl. of distillate. This pool is the result of seismograph exploration.

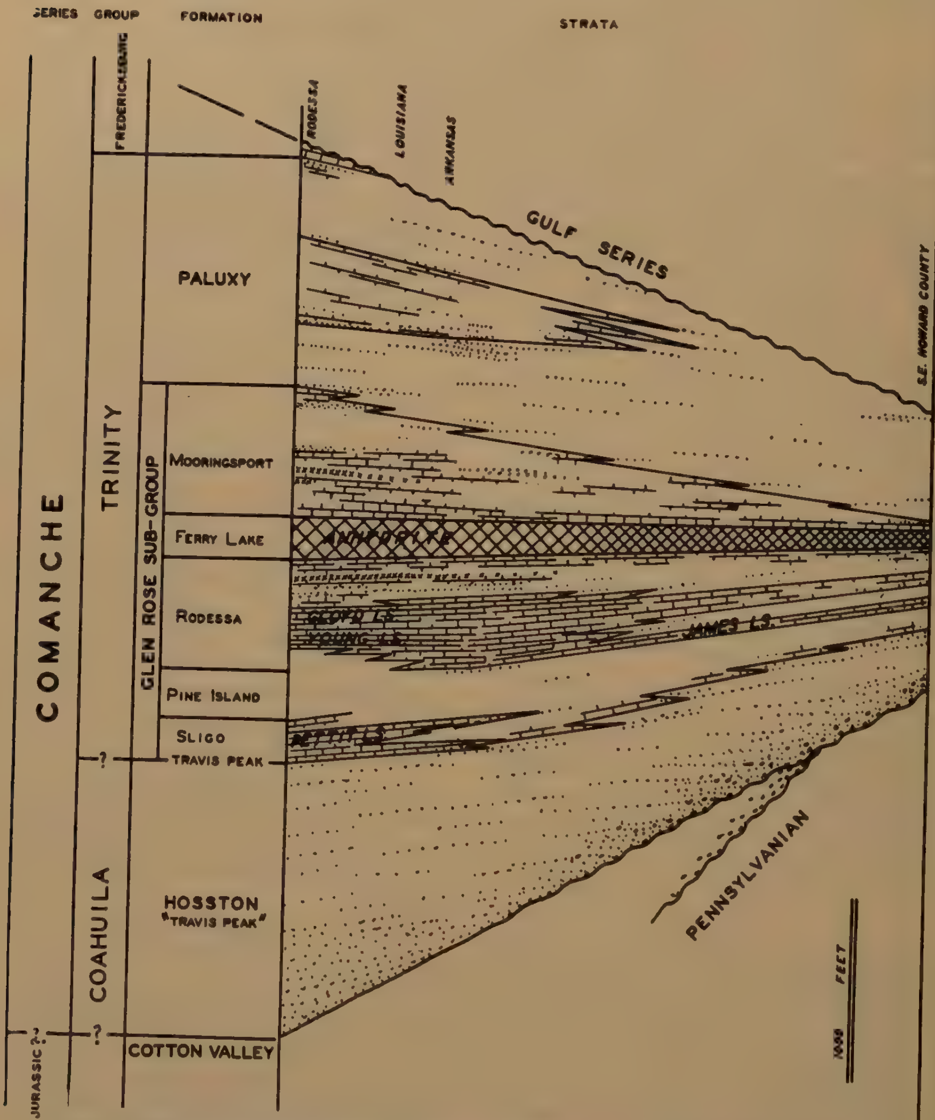

FIG. 1.—STRATIGRAPHIC SECTION, COMANCHE SERIES, SOUTHWESTERN ARKANSAS. Nomenclature after Shreveport Geological Society and Imlay.

Nick Springs.—The Delta Drilling Company's No. 1 Grace, sec. 31, T. 17 S., R. 14 W., central eastern Union County, was completed on June 1, 1940, producing 16 bbl. of 37° gravity oil and 34 bbl. of salt water per hour through ½-in. tubing choke

TABLE 1.—*Oil and Gas Production in South Arkansas*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940	
										During 1940		End of 1940			Number of Wells	
			Oil	Gas[b,4]	To End of 1940	During 1940	To End of 1940	During 1940[8]	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift
1	Atlanta, *Columbia*	1938	800	0	832,195	722,225	887*x*	722*x*	16	10	0	0	16	0	16	0
2	Big Creek, *Columbia*	1939	0[3]	40	25,575	24,955	511	499	1	0	0	0	0	1	1	0
3	Bradley, *Lafayette*	1925	80	0	186,705	0[6]	0	0	6	0	0	0	0	0	0	0
4	Buckner, *Columbia, Lafayette*	1937	1,300	0	1,842,240	804,045	460*x*	201*x*	23	4	0	0	23	0	21	2
5	Camden, *Ouachita*	1934	10	0	37,850	240	0	0	1	0	0	0	1	0	0	1
6	Champagnolle, *Union*	1927	2,040	*x*	14,621,780	434,835	*x*	*x*	237	0	4	14	79	1	0	79
7	Dorcheat, *Columbia*	1939	800	0	455,490	417,560	4,289*x*	4,175*x*	8	5	0	0	8	0	8	0
8	East El Dorado, *Union*[1]	1922	1,420	*x*	9,412,175	134,630	*x*	*x*	191	2	3	1	54	3	0	54
9	El Dorado (South), *Union*	1920	8,000	*x*	47,936,515	473,105	*x*	0	1,115	0	4	15	201	0	0	201
10	Fouke, *Miller*	1940	160[3]	0	45,565	45,565	2	2	2	2	0	0	2	0	1	1
11	Garland City, *Miller*[2]	1932	300	0	1,960,730	102,370	*x*	*x*	28	0	1	6	15	0	0	15
12	Irma, *Nevada*	1921	900	*x*	6,859,335[5]	204,820	*x*	0	150	0	0	3	74	0	0	74
13	Lewisville (Stamps), *Lafayette*	1939	400	0	366,820	232,700	225*x*	139*x*	18	7	0	1	17	0	0	17
14	Lisbon, *Union*	1925	2,700	*x*	6,707,180	79,755	*x*	0	356	0	11	3	136	0	0	136
15	Magnolia, *Columbia*	1938	4,600	1,200	11,102,975	7,376,925	9,618*x*	6,639*x*	116	34	1	0	115	0	115	0
16	McKamie, *Lafayette*	1940	0	400[3]	76,145	76,145	547*x*	547*x*	3	3	0	0	3	0	3	0
17	Mt. Holly (McDonald), *Ouachita*	1929	60	0	117,085	0[6]	0	0	6	0	0	0	0	0	0	0
18	Nick Springs, *Union*	1940	140	0	180,470	180,470[7]	0	0	13	13	0	0	13	0	1	12
19	Rodessa, *Miller*	1937	2,150	200	5,809,390	717,045	32,332	7,926	123	3	15		75	10	4	71
20	Schuler, *Union*	1937	5,450	400	20,477,975	6,576,785	24,325*x*	11,671*x*	177	6	0	0	174	0	159	15
21	Morgan sands	1937	350[3]	0	2,067,530	236,910	1,670*x*	185*x*	15	1	0	0	12	0	0	12
22	Jones sand	1937	4,000	200	16,075,835	5,345,515	20,348*x*	10,691*x*	146	5	0	0	146	0	143	3
23	Reynolds oölite	1937	1,100	200	2,334,610	994,360	2,307*x*	795*x*	16	0	0	0	16	0	16	0
24	Smackover, *Ouachita, Union*	1922	25,760	*x*	383,951,850	5,625,770	*x*	*x*	3,743	2	87	64	1,605	0	0	1,605
25	Heavy	1922	16,000	*x*	329,242,650	5,008,890	*x*	*x*	*y*	2	37	58	1,130	0	0	1,130
26	Light	1922	9,600	*x*	54,521,880	592,800	*x*	*x*	*y*	0	50	6	472	0	0	472
27	Snow Hill	1936	160	*x*	187,320	24,080	*x*	0	6	0	0	0	3	0	0	3
28	Stephens, *Columbia, Nevada, Ouachita*	1922	3,000	*x*	6,554,025	196,175	*x*	*x*	306	0	1	0	198	0	0	198
29	Troy, *Nevada*	1936	500	0	1,588,555	453,875	*x*	*x*	35	6	1	4	31	0	0	31
30	Urbana, *Union*	1930	500	0	5,418,610	493,105	*x*	*x*	69	21	0	0	52	0	14	38
31	Village, *Columbia*	1938	600	0	792,450	417,280	3,962*x*	2,036*x*	11	0	0	0	11	0	11	0
32	Total		61,670	2,640+	527,359,685	25,790,380	77,156+	34,557+	6,754	118	128	111	2,903	15	354	2,550

[b] Footonotes to column heads and explanation of symbols are given on page 256.

[1] Including several small producing areas.

[2] Includes the single Glen Rose producer in sec. 24, T. 15 S., R. 26 W., now abandoned.

[3] Areas of Big Creek, Fouke and McKamie are not yet fully defined. The area of the Morgan sands of Schuler may be considerably enlarged with future reworking of deeper wells.

[4] Big Creek and McKamie are classified as gas fields; however, the latter produces a considerable quantity of high-gravity oil or distillate. Although Dorcheat is officially termed an oil field, the fluid produced and the gas-oil ratios are comparable with those of McKamie. Village has relatively high gas-oil ratios. Magnolia and the Jones sand and Reynolds oölite of Schuler have gas caps which are not being produced.

[5] Includes 135 bbl. produced at Falcon in 1938.

[6] Fields abandoned in 1931.

[7] Producing from five sands in the upper part of the Hosston formation.

[8] With the exception of Big Creek and Rodessa, where approximate gauges are available, gas volume produced is estimated from average gas-oil ratios.

from depths between 3465 and 3490 ft. The discovery well was the second deep test for the area abandoned in the Smackover limestone and had been plugged back from a depth of 6819 ft. By the end of the year 180,470 bbl. of oil had been produced from 13 wells in five sands ranging in depth from 3150 to 3760 ft. within the upper half of the Hosston formation. Production lies in narrow bands in the various sands where upthrown against a fault. The drilling followed seismic exploration.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.		Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
									Depth, Avg. Ft.					
	Initial	Avg. at End of 1940	Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent[g]	Name	Age[e]	Character[f]	Porosity[g]	Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	3,844	3,733	42.6	0.49	Reynolds	Jur	OL	17.6	8,202	8,227	25	A	Smackover	8,332
2	3,723	*x*	68.7		Reynolds	Jur	OL	13.4	7,959	7,995	36	A	Smackover	7,999
3	*y*	*x*	26.3	0.43	Buckrange	CreU	S	Por	2,785	2,790	5	A	Paluxy	3,555
4	3,200	2,737	32.3	1.87	Reynolds	Jur	OL	15.0	7,200	7,260	30	A	Smackover	7,444
5	*y*	*y*	16.2	2.56	Nacatoch	CreU	S	Por	1,356	1,369	13	ML	Hosston	2,500
6	*y*	*y*	22.3–34.0	1.42–2.00	Tokio Travis Peak	CreU CreL	S	Por	2,780 3,340	2,800 3,350	15	NL	Eagle Mills salt	6,911
7	4,243	3,905	56.0	0.40	Reynolds	Jur	OL	15.0	8,815	8,875	60	A	Smackover	9,028
8	*y*	*y*	20.5	1.92	Nacatoch	CreU	S	Por	2,170	2,180	10	TL	Cotton Valley	6,003
9	*y*	*y*	32.7–33.2	1.07–1.15	Nacatoch	CreU	S	Por	2,100 2,550 2,950	2,177	20	ANL	Travis Peak	3,396
10	1,485	*y*	31.4		Paluxy	CreL	S	Por	3,583 3,655	3,607 3,660	24 5	F	Smackover	9,550
11	*y*	*y*	31.7–47.4	1.26–0.44	Paluxy Rodessa	CreL	S	Por	2,925 4,200	2,935 4,215	10	ML	Smackover	7,310
12	*y*	*y*	14.1	2.70	Nacatoch	CreU	S	Por	1,150	1,179	27	AF	Travis Peak	3,735
13	1,450*x*	*x*	42.6	0.63	Blossom Rodessa	CreU CreL	OL-S	17.0	3,400	3,500	20	TF	Smackover	7,420
14	*y*	*y*	34.0	1.08	Nacatoch	CreU	S	Por	2,100	2,120	20	ML	Smackover	6,821
15	3,555	3,237	38.0	0.89	Reynolds	Jur	OL	16.1	7,350	7,600	100	A	Smackover	7,824
16	4,365	4,365	58.3	0.24*x*	Reynolds	Jur	OL	Por	9,125	9,300	106	A	Smackover	9,366
17	*y*	*x*	30.0	*y*	Hosston	CreL	S	Por	2,800	2,813	7	ML	Hosston	3,378
18	1,600	1,541	34.1–39.6	*y*	Hosston	CreL	S	Por	3,153–3,736	3,161–3,762	30	AF	Smackover	6,819
19	2,500*x*	200*x*	39.4–44.9	0.29–0.38	Rodessa	CreL	LS-OL	5.0–30.0	6,050	6,100	25	AF	Rodessa	6,514
20														
21	2,000*x*	*x*	40.9–41.9	0.52–0.56	Cotton Valley	Jur	S	16.0	5,600	5,885	30	AL	Smackover	8,328
22	3,520	1,612	34.6	1.40	Cotton Valley	Jur	S	20.2	7,530	7,610	42	A	Smackover	8,328
23	3,545	3,385	36.8	0.91	Reynolds	Jur	OL	16.7	7,600	7,635	26	A	Smackover	8,328
24														
25	*y*	*y*	19.8–23.1	2.02 2.36	Nacatoch Graves Tokio	CreU	S	Por	2,000 2,450 2,600	2,025 2,475 2,610	40	Af	Eagle Mills salt	7,255
26	*y*	*y*	20.8–27.3	1.77–2.24	Nacatoch Meekin	CreU	S	Por	2,000 2,275	2,025 2,300	30	ALf	Igneous	7,973
27	*x*	*x*	36.2	1.08	Reynolds	Jur	OL	25.0	4,800	4,960	30	AF	Eagle Mills salt	5,708
28	*y*	*y*	12.6–30.6	2.87–1.60	Nacatoch Buckrange	CreU	S	Por	1,500 2,100	1,510 2,110	15 7	NLF	Smackover	6,053
29	*x*	*x*	14.1–22.0–	2.24–2.51	Nacatoch Tokio	CreU	S	Por	1,243 2,160	1,250 2,167	10	F	Eagle Mills salt	6,143
30	*x*	*x*	18.9–32.7	2.03–1.14	Nacatoch Hosston	CreU CreL	S	Por	2,270 3,550	2,280 3,560	10	A	Cotton Valley	4,501
31	3,350	3,310	41.1	0.80	Smackover	Jur	OL	14.0	7,390	7,450	50	A	Smackover	7,603
32											878			

[g] Most of the figures for sulphur content were obtained from O. C. Blade and G. C. Branner: Survey of Crude Oils of the Producing Fields of Arkansas. U. S. Bur. Mines *R. I.* 3486 (Jan. 1940).

Extensions and Development

Urbana.—Electric logging resulted in the discovery of two new producing sands in the old Urbana field around sec. 3, T. 18 S., R. 13 W., eastern Union County. The Marine Oil Company's No. A-12 Thompson was completed July 23, 1940, producing 5 million cubic feet of gas and 2 bbl. of 28° gravity oil per day through ¼-in. tubing choke at a depth of 3200 ft. A later well produced 114 bbl. of oil per day. On Aug. 1, 1940, the A-13 Thompson was completed from a sand at 3005 ft., producing 222 bbl. of 28° gravity oil per day through 13/64-in. Ten wells were completed in this sand by the end of 1940.

Other Fields.—As in the previous year, the *Magnolia* field, Columbia County, led in development with the completion of 33 oil wells from the Reynolds oölite. One dry hole was drilled. With 115 wells covering 4600 acres the field is practically developed. In the same county the *Atlanta* field had 10 oil wells and 2 dry holes, being defined at 800 acres. The *Buckner* field had 4 new oil wells, while *Dorcheat* had 4 wells and a dry hole. The latter, essentially a gas area, is only partly defined at 800 acres. Six wells were added to the shallow *Troy* field in Nevada County. Two small pumping wells were completed from the Blossom sand in the *Smackover* field, Ouachita County. One small Nacatoch well was added to the *East El Dorado* field, Union County.

Regulation of Production and Development

The Arkansas Oil and Gas Commission continued to regulate the drilling and producing in the new fields (discoveries since 1936). Spacing for the deeper oil fields, except the Jones sand of the Schuler field, continued to be on a 40-acre basis. The McKamie field has been designated a "gas field" and 160-acre spacing ordered for further development.

Early in 1941 plans were consummated for the unitizing of the Jones pool in the Schuler field. At the request of the majority of the leaseholders and royalty owners, the Oil and Gas Commission ordered unitization. Plans are to inject the residue gas into the gas cap of the Jones reservoir.

Table 2.—*Summary of Drilling Operations in South Arkansas*

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Surface Formation	Deepest Horizon Tested
		Sec.	Twp.	Rge.			
1	Arkansas	33	5 S	4 W	4,581	Quaternary	Pottsville (?)
2	Calhoun	17	15 S	13 W	4,790	Cockfield	Smackover
3	Columbia	5	19 S	18 W	8,760	Cockfield	Smackover
4	Columbia	24	17 S	19 W	7,768	Cockfield	Smackover
5	Columbia	12	18 S	23 W	9,065	Claiborne	Smackover
6	Columbia	10	18 S	20 W	8,405	Cockfield	Smackover
7	Craighead	35	14 N	3 E	5,092	Wilcox	Paleozoic
8	Lafayette	29	17 S	23 W	9,221	Claiborne	Smackover
9	Miller	1	17 S	27 W	9,550	Claiborne	Smackover
10	Nevada	2	11 S	21 W	1,300	Midway	Smackover
11	Nevada	9	15 S	22 W	6,068	Cane River	Smackover
12	Union	36	19 S	17 W	9,069	Cockfield	Smackover
13	Union	9	17 S	16 W	6,821	Cockfield	Smackover
14	Union	29	18 S	16 W	8,020	Cockfield	Smackover
15	Union	31	17 S	14 W	6,819	Cockfield	Smackover
16	Union	3	18 S	13 W	3,060	Cockfield	Hosston

Early in 1940 an attempt to force proration on the basis of sand thickness or oil in place failed.

Acknowledgments

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Table 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	J. M. Hazelwood						Dry hole
2	British-American Oil Co.						Dry hole
3	Barnsdall Oil Co.						Dry hole
4	J. M. Forgotson						Dry hole
5	Gulf Refining Co.						Dry hole
6	Louark Prod. Co.						Dry hole
7	Tennark, Inc.						Dry hole
8	The Atlantic Ref. Co.	240	1.996	11/64	3100	2950	Discovery, McKamie field
9	Louark Prod. Co.	100		3/16	185	150	Discovery, Fouke field. Deepest well in state
10	Coker Oil Co.						Dry hole
11	Texas-Canadian Oil Co.						Deep test, Falcon field. Dry hole
12	Barnsdall Oil Co.						Dry hole
13	E. G. Bradham, et al.						Deep test, Lisbon field. Dry hole
14	Louark Prod. Co.						Dry hole
15	Delta Drg. Co.	274		1	250	50	Discovery, Nick Springs field
16	Marine Oil Co.	222		13/64	950	550	New Horizon, Urbana field

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	16	21
Number of oil wells completed during 1940	111	3
Number of gas wells completed during 1940	2	0
Number of dry holes completed during 1940	18	35

Developments in California Oil Industry during 1940

By V. H. Wilhelm,* Member A.I.M.E.

(New York Meeting, February 1941)

Since 1935 California has enjoyed a remarkable cycle of discovery, which has placed the state in a very satisfactory position in regard to oil reserves. Most of the geophysical plays have been drilled and it is possible that new discoveries must be made by the application of careful geologic and stratigraphic studies.

During 1940 only one new field was discovered, which, although not of major importance, may lead to additional discoveries. During the year, 113 wildcats were drilled.

New discoveries, extensions and a reappraisal of discoveries made in 1939 will not approximate over 50,000,000 bbl., as against an estimated withdrawal during the year of 224,000,000 barrels.

Demand in terms of crude for 1940 was 632,000 bbl. per day as against 626,000 bbl. per day for 1939. Demand for gasoline was the same as in 1939, but the demand for fuel oil increased 3.8 per cent. Compared with 1939, Japanese shipments decreased from 75,786 bbl. per day to 61,000 bbl. per day, but the balance of Pacific foreign shipments increased from 59,409 bbl. per day to 61,304. Total withdrawals from storage during the year will approximate 7,000,000 bbl., almost all of which is fuel oil.

Drilling activity was slightly greater than in 1939 and accounted for 890 new producing wells as against 851 for 1939 (Table 3).

Production averaged 611,900 bbl. per day as compared with 614,842 bbl. per day for 1939.

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The productive acreage figure of the state was increased by 4000 through discoveries and extensions.

New Discoveries

Los Angeles Basin District

Del Valle Field.—Northwest of Newhall, where the first oil well in California was drilled, R. E. Havenstrite completed his Lincoln No. 1 well, flowing 390 bbl. of 50° gravity oil together with 7000 M cu. ft. of gas. Later the well was recompleted, after cutting off the gas, for 950 bbl. of 34° gravity oil. The type of structure from which this production is coming is a plunging anticline, complicated by faulting. The Lincoln No. 1 well uncovered approximately 180 ft. of net sand. This field contains a gas cap and its indicated productive area approximates 500 acres.

An intensive wildcat drilling campaign is expected during this coming year in the district in the vicinity of the Del Valle field.

Extensions and Deeper Sand Developments

Los Angeles Basin District

Athens Field.—On the northwest plunge of the Athens structure, the Thorley Oil Co. completed its No. 12-1 well, flowing 250 bbl. of 32° gravity oil from a depth of 8097 ft. The area in which the well is located is complicated by faulting and it is impossible at this date to determine the importance of this deep-zone discovery.

TABLE 1.—*Oil and Gas Production in California*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres	Total Oil Production, Bbl.	
			Oil[b]	To End of 1940	During 1940
	SAN JOAQUIN VALLEY				
1	Buena Vista, *Kern*	1909	22,000	276,816,802	5,843,518
2	Belridge, North, *Kern*	1912	1,837	40,239,507	3,855,165
3	Belridge, South, *Kern*	1911	2,300	22,324,731	745,969
4	Canal, *Kern*	1937	990	4,766,976	2,033,788
5	Coalinga, East, *Fresno*	1900	6,400	218,738,042	1,949,315
6	Coalinga, West, *Fresno*	1900	11,370	144,453,663	1,795,192
7	Coalinga, Nose, *Fresno*	1938	2,870	6,894,458	4,467,288
8	Coalinga, Northeast, *Fresno*	1939	1,560	1,845,080	1,663,255
9	Coles Levee, *Kern*	1938	2,910	1,703,433	1,356,868
10	Edison, *Kern*	1934	1,240	7,331,298	863,278
11	Elk Hills, *Kern*	1919	7,870	154,245,824	4,424,902
12	Fruitvale, *Kern*	1928	2,050	22,301,959	2,040,337
13	Greeley, *Kern*	1936	1,900	3,977,026	1,470,823
14	Kern Front, *Kern*	1925	3,960	45,467,660	2,169,450
15	Kern River, *Kern*	1899	6,100	275,944,787	1,464,416
16	Kettleman, Middle, *Kern*	1932	200	533,811	
17	Kettleman, North, *Kern, Fresno*	1928	16,190	238,228,073	16,719,389
18	Lost Hills, *Kern*	1910	2,600	50,045,409	1,372,860
19	McKittrick, *Kern*	1887	1,525	90,970,410	1,301,933
20	Midway-Maricopa, *Kern*	1901	32,480	618,189,802	12,539,782
21	Mountain View, *Kern*	1933	1,955	38,244,132	3,000,610
22	Mt. Poso Dist., *Kern*	1926	2,600	53,786,875	3,815,242
23	Paloma, *Kern*	1939	2,000	152,527	129,320
24	Richfield Western, *Kern*	1938	1,700	1,418,972	1,228,571
25	Rio Bravo, *Kern*	1937	2,075	8,238,148	3,295,054
26	Round Mountain, *Kern*	1927	1,720	27,951,867	2,664,394
27	Strand, *Kern*	1939	320	668,100	530,161
28	Ten Sections, *Kern*	1936	2,200	10,353,299	3,516,435
29	Wasco, *Kern*	1938	375	1,094,014	566,776
30	Wheeler Ridge, *Kern*	1922	220	3,816,562	112,833
31	Others			314,849	55,183
32	San Joaquin Valley, total		143,517	2,371,058,096	86,992,107
	COASTAL DISTRICT				
33	Capitan, *Santa Barbara*	1929	296	4,906,624	650,852
34	Elwood, *Santa Barbara*	1928	400	67,256,269	1,286,761
35	Santa Barbara, *Santa Barbara*	1929	165	3,279,922	84,365
36	Summerland, *Santa Barbara*	1894	180	3,153,813	8,037
	SANTA MARIA DISTRICT				
37	Casmalia, *Santa Barbara*	1904	1,010	*t*	118,768
38	Cat Canyon, *Santa Barbara*	1908	1,430	*t*	276,454
39	Gato Ridge, *Santa Barbara*	1931	360	(4,201,876)	891,153
40	Lompoc, *Santa Barbara*	1903	2,215	*t*	99,332
41	Orcutt, *Santa Barbara*	1903	4,220	*t*	808,583
42	Santa Maria Valley, *Santa Barbara*	1934	5,230	(15,300,967)	6,061,273
42a	Santa Maria District			159,061,007	
	VENTURA DISTRICT				
43	Padre Canyon, *Ventura*	1936	180	1,340,858	311,102
44	Rincar, *Ventura*	1927	425	12,544,813	1,581,230
45	San Miguelito, *Ventura*	1931	180	4,804,505	877,965
46	Ventura Avenue, *Ventura*	1916	1,840	225,787,028	12,548,184
	VENTURA-NEWHALL DISTRICT				
47	Aliso Canyon, *Los Angeles*	1938	150	(755,961)	527,783
48	Bardsdale, *Ventura*	1894	287	*s*	49,666
49	Del Valle, *Los Angeles*	1940	500	(30,691)	30,691
50	Elsmere Canyon, *Los Angeles*	1889	230	*s*	0
51	Ex-Mission, *Ventura*	1875	130	*s*	10,282

[b] Footnotes to column heads and explanation of symbols are given on page 256.
t, with Santa Maria district.
ι, with Ventura-Newhall.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: During 1940: Abandoned	Number of Oil and/or Gas Wells: End of 1940: Temporarily Shut Down	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Number of Oil and/or Gas Wells: End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Pump & G.L. Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average: Max.	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average: Min.	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent
1	With Midway-Maricopa					249			2	645				28	22	26.6	
2	256,459	43,654		13		42			64	11				41	30	36	0.56
3						48			1	215				26	14	24	
4	With Strand			7		10			27	1	3,600			38	36	37.5	
5				3	15	431				169				24	19	21	
6				2		106				622				23	12	15.8	0.45
7	10,203	8,806		49		2			97		3,380	3,290		34	28	33	
8				41					50						27	28	
9	4,601	4,601		20	3	3			30	3				34	28	33	
10	With Mt. View			11	3	6				98				26	15	18.5	
11	78,758	2,846				56				193				25	15	22.1	0.57
12				1	6	21			12	146				24	14	19.8	0.60
13	15,096	2,263		18	1	2			32	8				60	32	35.5	0.28
14				2		80				371				15	12	14.4	
15				25	11	938				1,268				14	12	13.3	
16	14,065					1								58	48	55.1	
17	1,397,133	87,861		39	4	48			109	152	{3,150 4,500}			37	34	36.5	0.30
18		499		1	1	127				279				36	13	18	
19				9		119				206				18	13	14.2	
20	363,222	12,055		26	34	877			1	1,852				28	12	17.5	0.65
21	47,339	3,057		3	16	7				174				26	21	26	0.44
22				6	7	60				352				16	14	15.2	
23				4					5		4,820			48	55	51	
24				38					42					33	45	40	
25	6,981	3,674		34	2				73					48	38	38.5	
26				5	7	24				211				17	13	16.5	
27	3,028	2,907		5		2			8							34	0.37
28	16,226	4,099		38		3			80		3,600			38	33.8	35.4	
29				5	1				12					38		37.7	
30					1					34				23	23	23.5	
31		799		3	1	32			1	9							
32		177,121				3,294			646	7,019							
33	3,077	551			2	9			1	44				43	18	28	
34	60,846	1,940			1	13			1	68				41	22	33.7	
35				1	11	2				21				19	14	17	
36					4	6				1				19	17	18	0.84
37						58				6				20	8	10.3	2.1
38				1		56				10				15	10	13.5	4.5
39				2		7				12				14	13	13.9	
40						28				7				21	20	20.5	4.4
41				2		99				128				26	18	22.6	1.6
42		2,284		13	2	24			52	87				17	13	15.9	
42a					6												
43	} 14,625	2,131		{4					2	12				31	28	29.1	
44				13					13	60				30	27	30	
45	6,298	790		8		1			18	2				34	29	30	
46	777,947	33,026		43	2	86			140	198				50	12	30	
47				8		3			9					54	23	24	
48						9			1	24				33	22	32.1	1.7
49									1							32	
50						9								23	14	16	0.72
51										24				28	24	24.5	0.70

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft. Sand	Structure[h]	Name	Depth of Hole, Ft.
1	Etchegoin	Pli	S	15.1	2,665	3,500	65	A	Miocene	11,720
2	Etchegoin, Temblor, Vaqueros	Pli-Mio	S	15.1	4,917	7,152	500	A	Eocene	9,682
3	Etchegoin-Temblor	Pli-Mio	S		810	874	50	A	Miocene	11,377
4	Stevens	Mio	S	20	8,250	8,297	190	A	Miocene	8,350
5	Etchegoin-Temblor	Pli-Mio	S	25	1,860	2,076	70	AUP	Cretaceous	9,418
6	Etchegoin-Sta. Margarita	Pli-Mio	S		900	1,580	80	MUP	Cretaceous	4,883
7	Avenal	Eoc	S	22	6,400	7,440	360	MU	Eocene	8,416
8	Avenal	Eoc	S	25	8,100	8,208	130	MU	Cretaceous	9,614
9	Stevens	Mio	S	24	8,070	9,621	100	MU	Miocene	9,777
10	Kern River-Temblor	Pli-Mio	S		2,000	2,239	125	MU	Granite	800
11	Etchegoin	Pli	S		2,600	3,115	55	A	Miocene	8,404
12	Etchegoin-Chanac	Pli	S		3,000	3,685	88	MU	Schist-Jurassic	8,531
13	Stevens-Vedder	Mio	S	22	7,720 11,430	7,800 11,500	45 95	AM	Lower Miocene	12,504
14	Etchegoin	Pli	S		1,700	2,175	60	MF	Miocene	2,650
15	Kern River	Pli	S		400	837	300	MU	Oligocene	4,852
16	Temblor	Mio	S		7,350	7,285	57	A	Miocene	9,138
17	Temblor-Avenal	Mio-Eoc	S	16	6,300 10,200	8,236 10,851	300 45	A	Eocene	11,746
18	Etchegoin	Pli	S		1,170	1,204	80	A	Miocene	7,858
19	Etchegoin	Pli	S		800	1,107	90	MUF	Miocene	6,664
20	Etchegoin-Maricope	Pli-Mio	S		1,950	2,095	65	MF	Miocene	9,735
21	Chanac-Sta. Margarita	Pli-Mio	S		5,140	5,589	70	MF	Miocene	8,419
22	Vedder	Mio	S	35	1,600	1,745	90	MF	Granite	3,130
23	Stevens	Mio	S	20	10,030	10,175	122	A	Miocene	11,216
24	Stevens	Mio	S	24	8,790	9,580	600	MU	Miocene	10,120
25	Vedder	Mio	S		11,249	11,495	200	A	Eocene	14,108
26	Jewett, Vedder	Mio	S	34	1,600	1,861	66	MF	Oligocene	6,070
27	Stevens	Mio	S		8,200	8,325	50	D	Miocene	11,260
28	Stevens	Mio	S	22	7,850	8,216	200	A	Miocene	8,984
29	Vedder	Mio	S	18	13,100	13,143	32	A	Eocene	15,004
30	Etchegoin-Sta. Margarita	Pli-Mio	S	26	2,000	2,717	y	A	Oligocene	11,204
31										
32										
33	Vaqueros-Sespe	Mio-Olig	S		1,150	1,400 2,734	305	AF	Sespe	4,071
34	Monterey-Vaqueros-Sespe	Mio-Olig	S	25	2,800	3,128 3,906	320	AF	Eocene	7,157
35	Vaqueros	Mio	S		1,960	2,003	45	MF	Sespe	4,730
36	Pliocene-Vaqueros	Pli-Mio	S		400	1,600	y	A	Sespe	5,041
37	Monterey	Mio	H		1,200	1,679	Fis	A	Miocene	3,900
38	Monterey	Mio	H		2,000	3,000	Fis	A	Cretaceous	7,199
39	Monterey	Mio	H		1,800	3,255	Fis	AF	Vaqueros, Miocene	6,510
40	Monterey	Mio	H		2,200	2,711	Fis	A	Miocene	4,310
41	Monterey	Mio	S, H		1,100	3,175	Fis	A	Sespe, Oligocene	5,815
42	Monterey	Mio	S, H		4,000	4,488	Fis	MU	Franciscan	8,133
42a										
43	Repetto	Pli	S		4,800	5,872	350	AF	Miocene	6,566
44	Repetto	Pli	S		2,500	4,000	y	A	Pliocene	7,291
45	Repetto	Pli	S		5,500	7,042	680	AF	Pliocene	10,030
46	Repetto	Pli	S		3,400	6,244 7,188 9,240	6,629 3,000	A	Pliocene	11,070
47	Repetto-Modelo	Pli-Mio	S		4,795	5,287	200	M	Miocene	8,200
48	Sespe-Tejon	Olig-Eoc	S		500	888	y	A	Eocene	6,804
49	Modelo	Mio	S		6,037	6,954	180	A	Miocene	6,954
50	Repetto	Pli	S		240	800	y	MU	Jurassic schist	2,117
51	Repetto	Pli	S		500	1,585	y	MF		

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940
52	Hopper Canyon, *Ventura*	1887	153	[g]	48,490
53	Modelo, *Ventura*	1898	60	[g]	4,622
54	Newhall Potrero, *Los Angeles*	1937	156	(1,277,138)	605,384
55	Oxnard, *Ventura*	1937	490	[g]	89,140
56	Pico Canyon-Newhall, *Los Angeles*	1875	110	[g]	36,004
57	Sespe, *Ventura*	1887	289	[g]	91,314
58	Shiells Canyon, *Ventura*	1911	510	(10,149,344)	421,978
59	Simi, *Ventura*	1912	635	[g]	31,624
60	Sisar-Silverthread, *Ventura*	1885	330	[g]	42,916
61	South Mountain, *Ventura*	1916	785	(21,854,398)	572,260
62	Sulphur Mt., *Ventura*	1927	40	[g]	2,767
63	Tapo-Eureka, *Ventura*	1882	224	[g]	9,834
64	Temescal, *Ventura*	1924	120	[g]	221,535
65	Timber Canyon, *Ventura*	1885	110	[g]	9,570
66	Fresno-Lion Mt., *Ventura*	1917	50	[g]	11,199
67	Torrey Canyon, *Ventura*	1896	140	[g]	58,523
68	Wiley-Towsley Canyon, *Los Angeles*	1887	28	[g]	3,604
68a	Ventura Newhall District		(4,690)	65,064,425	
	OTHER COASTAL COUNTIES				
69	Edna, *San Luis Obispo*	1929	25	736,253	6,572
70	Pismo, *San Luis Obispo*	1928	200	96,838	13,468
71	Half Moon Bay, *San Mateo*	1886	80	40,863	1,588
72	Sargent-Los Gatos, *Santa Clara*	1886	60	363,049	12,658
73	Coastal District total		24,023	548,436,267	28,523,795
	LOS ANGELES BASIN				
74	Alamitos, *Los Angeles*	1931	85	23,743,154	454,025
75	Brea Olinda, *Orange*	1889	1,900	165,843,345	2,026,940
76	Coyote, East, *Orange*	1911	1,080	81,097,370	1,360,669
77	Coyote, West, *Orange*	1909	985	83,495,714	2,653,159
78	Dominguez, *Los Angeles*	1923	1,054	121,776,268	7,660,340
79	El Sagundo, *Los Angeles*	1935	930	9,615,162	777,708
80	Huntington Beach, *Orange*	1920	2,100	290,318,848	9,494,637
81	Inglewood, *Los Angeles*	1924	780	120,803,397	4,363,977
82	Lawndale, *Los Angeles*	1928	72	1,060,287	14,543
83	Long Beach, *Los Angeles*	1921	1,600	649,147,806	15,801,432
84	Los Angeles Dist., *Los Angeles*	1892	1,627	65,844,277	179,414
85	Montebello, *Los Angeles*	1917	1,658	122,389,875	7,180,973
86	Playa del Rey, *Los Angeles*	1934	615	46,200,056	1,462,182
87	Potrero, *Los Angeles*	1928	120	3,567,044	680,527
88	Richfield, *Orange*	1919	1,290	89,644,290	2,973,180
89	Rosecrans-Athens, *Los Angeles*	1924	790	44,748,373	4,180,094
90	Santa Fe Springs, *Los Angeles*	1919	1,630	468,638,053	9,429,736
91	Seal Beach, *Los Angeles*	1926	240	63,672,983	2,094,735
92	Torrance, *Los Angeles*	1922	6,905	101,062,314	3,913,970
93	Whittier, *Los Angeles*	1898	600	18,245,827	185,731
94	Wilmington, *Los Angeles*	1935	4,400	109,478,802	30,131,651
95	Others, *Los Angeles*			2,799,106	248,861
96	Los Angeles Basin total		30,461	2,683,192,351	107,268,484
97	STATE TOTAL		198,001	5,602,686,714	222,784,386

GAS FIELDS

Line Number	Field, *County*	Year of Discovery	Gas[b]		B.t.u.
	NORTHERN GROUP				
98	Eureka, *Humboldt*	1937	800		940
99	McDonald Is., *San Joaquin*	1936	1,500		965
100	Potrero Hills, *Solano*	1938	100		941
101	Rio Vista, *Sacramento, Solano*	1936	20,000		1,040
102	Sutter Buttes, *Sutter*	1933	120		1,016
103	Tracy, *San Joaquin*	1935	500		935
104	Willows, *Glenn*	1938	100		990
105	Fairfield Knolls, *Yolo*	1939	150		935
	SAN JOAQUIN VALLEY				
106	Buena Vista Lake, *Kern*	1934	1,050		1,000
107	Buttonwillow, *Kern*	1926	1,700		985
108	Chowchilla, *Madera*	1935	300		930
109	Trico, *Kern*	1935	6,600		980
110	Semitropic, *Kern*	1932	3,750		980
	COASTAL				
111	Goleta, *Santa Barbara*	1929	1,035		1,035

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil			
				During 1940		End of 1940			Number of Wells								
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Pump & G.L. Artificial Lift	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average			Sulphur, Per Cent
52										13				31	18	29	
53						4				12				26	26	26.1	
54				8		1			14					35	33	33.3	
55						1				2				8	8	8	
56						38				20				35	33	33.3	
57				2		13				18				36	28	35.1	
58	With So. Mountain			6		17			6	109			SR	33	33	33.3	
59						59				51				31	16	28.1	
60						37				38				24	15	18.5	
61	61,651	4,163		2		5				90			SR	27	20	23.9	
62										1				16	15	15.5	
63										21				22	21	22.4	
64							14			14				24	21	22.0	
65							9			9				34	25	28.7	
66						1	16			16				23	20	22.7	
67						2	41			39				27	28	27.5	
68						9	13			4				27	20	23.6	
68*a*					14												
69						6	9			9				14	13	13.3	
70						4	4			4						22	
71					1	11				2						54	
72						13				10						13	
73		44,885				631			258	1,186							
74					5	1			1	39				29	16	26.8	
75	56,949	1,667		2	4	116				303				31	14	22.5	0.41
76	49,429	2,321		12		30			1	96			SR	26	18	25	
77				2		77			6	73			RP	31	24	28.9	
78	199,679	12,494		28	3	51			53	162				33	28	30.4	
79	7,166	385			7	4				41				29	15	21.8	
80	299,336	9,451		34	13	112			5	590				27	11	23.5	
81	88,762	3,297		3		95			26	172				38	14	22	
82					5					4				32	26	29	
83	857,299	14,918		29	30	29				1,248				32	12	25	
84					8					85				17	13	13.7	1.0
85	80,666	33,120		37	4	61			117	242				39	13	30	
86	48,500	1,212			9	9				158				24	11	21	2.7
87				6					6	15				48	33	44	
88	82,573	2,862		2	4	13				294				25	14	20.5	
89	110,128	13,063		35		13			18	155				42	31	33	
90	665,868	7,664			12	59				588				38	28	32.5	
91	97,038	3,323		5		21			5	70				29	16	23	
92	73,952	4,006		3	90	60			2	648				30	13	22	1.9
93				2	2	134				44				29	14	19	0.7
94	64,724	25,019		158	3	12			522	394	1,700	1,000		28	13	21	2.5
95		550		7		6				69							
96		135,352		365	199	903			762	5,490							
97																	
								GAS FIELDS									
98		57	3					1			2,500						
99	26,024	8,020	6					5									
100			1		1												
101	20,114	8,214	28	4	1			28			1,717	1,705					
102	2,560	1,228	4					3			2,950						
103	8,975	907	6	0	0			4			1,700	1,110					
104			1														
105	14		2								1,450						
106	3,420	831	6	1													
107	18,180	1,439	27		2			3			1,260	700					
108			3					3									
109	6,550	2,365	21	10				21									
110	3,701	883	22								1,275						
111	14,887		4		1						1,800	1,450					

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft. Sand	Structure[h]	Name	Depth of Hole, Ft.
52	Modelo	Mio	S		1,500	1,828	y	A		2,200
53	Modelo	Mio	S		180	2,050	y	A		1,488
54	Modelo	Mio	S		6,160	6,917	y	AF	Miocene	7,421
55	Modelo	Mio	S		2,100	2,905	y	MU	Miocene	4,285
56	Modelo	Mio	S		858	1,611	y	A	Eocene	4,300
57	Sespe	Olig	S		400	1,651	y	A, S	Oligocene	3,595
58	Sespe	Olig	S		100	2,000	640	A	Eocene	7,423
59	Meganos	Eoc	S		1,100	1,213	y	A		3,934
60	Sespe	Olig	S		315	683	y	MF		
61	Sespe	Olig	S		2,200	3,362	956	A	Eocene	6,702
62	Modelo	Mio	S		2,000	2,500	Fs	ML		
63	Modelo-Sespe	Mio-Olig	S		500	995	y	A		2,956
64	Modelo	Mio	S		2,000	2,411	y	A	Miocene	4,584
65	Repetto-Modelo	Pli-Mio	S		300	2,605	y	MF	Miocene	3,300
66	Modelo	Mio	S		844	1,044	y	ML		
67	Vaqueros-Sespe	Mio-Olig	S		700	1,363	y	AF		2,500
68	Modelo	Mio			600	1,016	y	AF		4,400
68a										
69	Monterey	Mio	H		800	1,200	y	A, S	Jurassic schist	2,125
70	Monterey	Mio	S			2,900	y	S		
71	Purissima-Monterey	Pli-Mio	SH		1,379	1,600	y	ML	Miocene	7,982
72	Monterey	Mio	SH		900	1,500	y	AF		
73										
74	Repetto-Puente	Pli-Mio	S		4,635	5,810	150	AF	Miocene	9,054
75	Repetto-Puente	Pli-Mio	S		260	3,026	800	AF	Miocene	8,021
76	Repetto-Puente	Pli-Mio	S		2,450	3,607	153	AF	Miocene	9,084
77	Repetto-Puente	Pli-Mio	S		2,800	4,471	473	D	Miocene	8,144
78	Repetto-Puente	Pli-Mio	S	28	3,800	5,189	1,900	AF	Miocene	12,120
79	Puente-Schist	Mio-Jur	S-Fis		6,890	7,316	100	A	Franciscan schist	8,009
80	Repetto-Puente	Pli-Mio	S	33	1,900	4,009	490	AF-MF	Miocene	9,054
81	Repetto-Topango	Pli-Mio	S		1,073	2,597	1,165	AF	Miocene	8,760
82	Repetto-Topango		S		6,375	5,841	y	MU	Miocene	7,405
83	Repetto-Topango		S	30	2,377	5,264	1,600	AF	Miocene	10,720
84	Repetto-Topango		S		475	1,045	y	AF	Miocene	5,074
85	Repetto-Topango		S		1,730	4,422	850	A	Miocene	8,468
86	Repetto-Topango	Pli-Mio	S		3,350	5,371	90	A	Franciscan schist	7,048
87	Repetto-Topango	Pli-Mio	S	29	3,640	5,605	400	AF	Miocene	8,376
88	Repetto-Topango	Pli-Mio	S		2,900	4,057	300	A	Oligocene-Sespe	10,496
89	Repetto	Pli-Mio	S	22	4,035	6,150	210	AF	Miocene	10,389
90	Repetto	Pli-Mio	S	29	3,470	5,373	490	D	Miocene	11,314
91		Pli-Mio	S		4,314	5,441	200	AF	Miocene	9,054
92	Miocene	Mio	S	27	2,637	4,220	260	AF	Franciscan schist	6,957
93	Repetto-Puente	Pli-Mio	S		200	2,109	270	MUF	Miocene	5,040
94	Repetto-Puente	Pli-Mio	S	28	2,320	3,631	423	AF	Franciscan schist	6,814
95						2,314				
96										
97										
	GAS FIELDS									
98	Repetto	Pli	SH	26	3,800	4,900	110	A	Pliocene	7,708
99	Capay	Eoc	S		5,178	5,216	38	D	Cretaceous	8,810
100	Cretaceous	Cre	S		3,235	3,265	30	D	Cretaceous	5,334
101	Domingine-Ione	Eoc	S	35	3,800	4,344	240	AF	Cretaceous	7,029
102	Cretaceous	Cre	S		2,700	5,855	87	MU	Intrusive rock	6,900
103	Cretaceous	Cre	S	32	3,926	4,070	100	D	Cretaceous	9,690
104	Cretaceous	Cre	S		2,345	2,360	10	D	Cretaceous	6,014
105	Cretaceous	Cre	S		3,651	3,682	30	A	Cretaceous	5,181
106	Etchegoin	Pli	S		4,117	5,219	20	AF	Miocene	11,186
107	Etchegoin	Pli	S		2,500	2,750	10	D	Pliocene	4,946
108	Eocene Cretaceous	Eoc Cre	S		2,611 7,900	2,923 8,125	63 140	D	Cretaceous	8,377
109	Etchegoin	Pli	S		2,420	3,150	14	A	Miocene	11,468
110	Etchegoin	Pli	S		2,275	3,215	5	A	Miocene	9,700
111	Vaqueros	Mio			4,139	4,533	354	AF	Eocene	6,912

TABLE 2.—*Summary of Drilling Operations in California*

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Deepest Horizon Tested	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Sec.	Twp.	Rge.				Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	Fresno......	14	20 S	18 E	10,747	Miocene	The Texas Company						Deep test Boston Land Co. Dry hole
2	Fresno......	29	14 S	13 E	8,730	Cretaceous	A. T. Jergins Trust	15 bbl. per day condensate	1.3	32/64	325	100	Cheney Ranch
3	Fresno......	23	17 S	15 E	10,116	Cretaceous	The Texas Company	15 bbl. per day condensate		1/64	700	100	Discovery well Turk anticline
4	Fresno......	4	22 S	16 E	11,020	Cretaceous	Continental Oil						Deep test Jacalitos dome. Dry hole
5	Fresno......	24	17 S	15 E	10,307	Eocene	The Texas Company						Deep test Turk anticline. Dry hole
6	Kern.......	13	11 N	22 W	13,873	Miocene	Shell Oil Co.						Deep test San Emidio dist. Dry hole
7	Kern.......	23	29 N	24 W	12,144	Miocene	Union Oil Co.						Deep test Buttonwillow. Dry hole
8	Kern.......	1	32 S	24 E	11,743	Miocene	General Petroleum Corp.						Deep test E. Flank B. V. Hills. Dry hole
9	Kern.......	12	28 S	24 E	13,028	Lower Miocene	Continental Oil						Deep test Shafter dist. Dry hole
10	Kern.......	22	29 S	17 E	10,590	Basement Complex	Western Gulf Oil						Deep test Fruitvale field. Dry hole
11	Kern.......	4	22	19	11,885	Vaqueros (Mio)	Shell Oil Company						Deep test Tulare lake. Dry hole
12	Los Angeles.	16	4 N	17 W	6,954	Miocene	R. E. Havenstrite	504	0.25	32/64	2,300	175	Discovery well Del Valle field
13	Los Angeles.	17	2 S	14 W	8,760	Miocene	R. R. Bush	700	0.75	29/64	700	0	Disc. well, Miocene zone, Inglewood field
14	Los Angeles.	7	3 S	13 W	8,097	Miocene	Thorley Oil Co.	360	0.225	36/64	500	50	Deep test Athens-Rosecrans

Number of dry holes completed during 1940: wildcats, 114 (583,537 ft.).

TABLE 3.—*California Oil-field Development Table*

Year	Number Drilling Notices Filed	Number Drilling Wells Abandoned	Number Producers Abandoned	Number Producers Completed (New Wells)	Percentage of Increase or Decrease[1]	Initial Production of New Wells, Daily Average, Bbl.	
						Per Well	Total
1930	918	254	320	755	17[1]	775	584,521
1931	329	238	177	246	67[1]	1,481	364,434
1932	279	191	172	184	25[1]	852	156,823
1933	596	163	215	248	35	1,105	274,104
1934	631	247	200	449	81	1,190	534,508
1935	986	347	203	710	37	954	677,320
1936	1,102	320	208	786	11	471	370,227
1937	1,643	313	273	1,156	47	560	647,331
1938	1,162	265	252	994	14[1]	1,242	1,234,482
1939	1,174	251	274	851	14[1]	1,314	1,118,102
1940	1,040	172	336	890	5	1,428	1,270,756

[1] Decrease.

Inglewood Field.—The Bush Oil Co. discovered a new deep Miocene zone in the Inglewood field by completing its Sentous No. 1 well on the west flank of the field for 150 bbl. of 32° gravity oil from a depth of 8760 ft. The well is on the edge of the structure and indications are that the substantial production from this zone will be obtained at higher structural positions. The producing zone in the Bush well is considered to be Topango, or middle, Miocene, and is the first production from this zone in the Los Angeles Basin. Deep drilling on the Inglewood structure shows that the fold is very asymmetrical at depth, with a steeply dipping east flank.

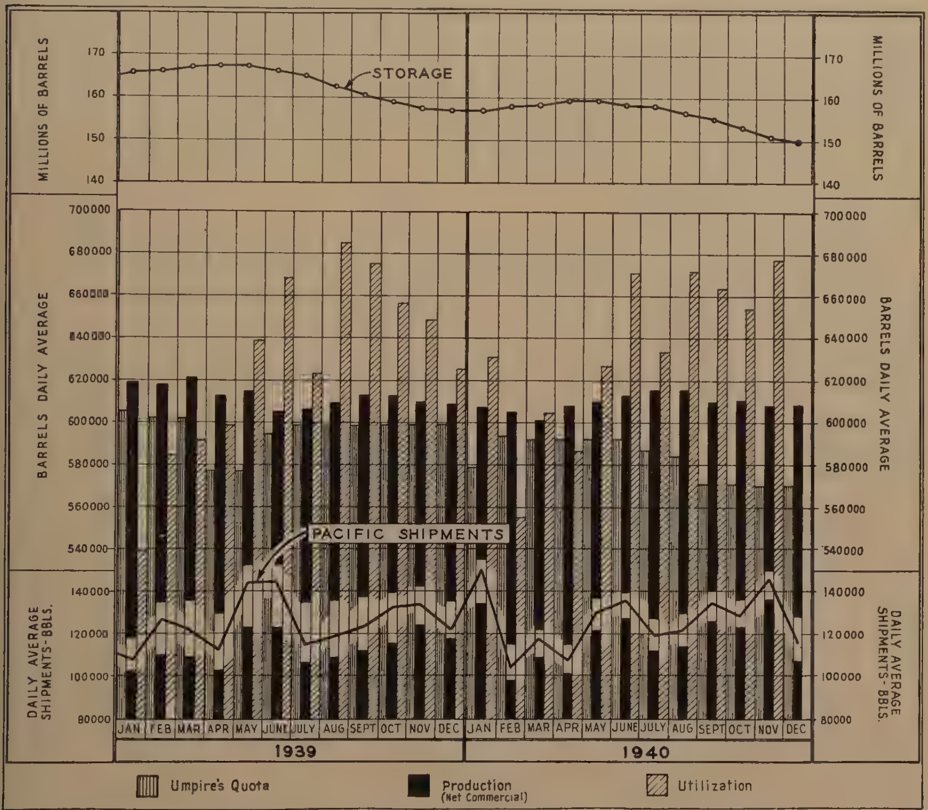

FIG. 1.—PRODUCTION, SHIPMENTS AND STORAGE OF OIL, CALIFORNIA.

Rosecrans Field.—On the southeast plunge of the Rosecrans field, an additional fault-line extension was discovered, yielding 1500-bbl. wells of 32° gravity oil from the Miocene beds. This discovery has expanded the limits of the field by about 50 acres.

Wilmington Field.—The Wilmington field was the most active in the state in 1940, completions for the year amounting to 158. A considerable area remains undeveloped and indications are that 1941 will see activity in proportion to that of 1940. An extension of this field to the northwest indicates that the Torrance and Wilmington fields will be contiguous.

SAN JOAQUIN VALLEY DISTRICT

Coles Levee and Richfield Western Fields. Fifty-eight wells were completed in these

two fields during 1940. The area comprising these fields was the second most active area in the state. Development to date shows that the Coles Levee and Richfield Western fields are separate structures. The Coles Levee field is an overlap accumulation with about 2915 proved acres, while the Richfield Western field is an anticline with approximately 1730 proved acres.

Midway-Sunset Field.—The Republic Petroleum Co. discovered a small closed structure in the Santa Margarita shale, west of Taft, by the completion of its No. 1 well. This well was brought in on the pump for 165 bbl. of 17.5° gravity oil from a depth of 1887 ft., producing from about 60 ft. of net sand. The productive area of this accumulation is estimated at 80 acres.

Paloma Field.—Paloma field, discovered in 1939, now has five producing wells. Data recently developed indicate a large productive area. This is the first distillate field in California to be recognized as such in advance of developments.

If an agreement between all operators in this field can be concluded, the gas will be recycled in order to obtain the greatest ultimate recovery.

Curtailment

Voluntary curtailment continued to be effective, and although production was generally above the state quota the average was well below the state market demand, as evidenced by the decrease in total stocks. During the year the top allotment to new wells was decreased from 195 bbl. per day in January 1940 to 148 bbl. per day in January 1941, a drop of 47 bbl. per day in 12 months. During the same period the state quota set by the Conservation Committee of California Oil Producers decreased from 594,000 bbl. per day to 570,000.

New completions during 1941 will require approximately 80,000 bbl. of new allotment. Decline, suspensions and abandonments will average 5000 bbl. a month, or 60,000 bbl. of allotment during the year. Therefore the 938 top wells and the 8000 intermediate wells must be declined to make room for this 20,000 bbl. of new allotment, unless conditions warrant an increase in the state quota of 570,000 bbl. If this is done, the top allotment probably will not be decreased below the present allotment of 148 bbl. per day.

Advances in Drilling and Production Practices

The past year showed a continuation of recent year trends in drilling and producing equipment and methods, chiefly the closer application of engineering principles toward individual jobs rather than the system of the past of applying the same method to all types of drilling. Outstanding has been the reduction of cost and drilling time in deep wells by means of engineering analysis of performance data and records of drilling aids such as gauges of table speed, drilling weight, pump speed and mud properties.

The cost of drilling shallow marginal wells has been cut sharply by the use of portable and semiportable drilling machinery driven by gas engines. Whenever the market for oil becomes stronger, it is probable that a considerable number of shallow wells of this type may be drilled in some of the older fields.

Producing methods have followed the same trend as drilling; that is, application of engineering to individual problems. Larger volumes of oil from deep wells are being pumped with equipment of conventional type. A means of pumping new marginal wells cheaply is still urgently needed, since the cost of satisfactory pumping equipment is excessive as compared with the new lower drilling costs.

Conclusion

Because of lack of proved locations in the state, it is estimated that not more than 700 new wells will be completed in 1941. Increased wildcat activity and repair of old

wells will probably bring activity up to normal.

Pacific shipments probably will be decreased about 20,000 bbl. per day, owing to additional shipments to Japan from the Dutch East Indies. Readjustment of Pacific markets will compensate to some extent for loss of Japanese shipments.

Increased industrial activity will tend to raise domestic demand sufficiently to make up for loss in Pacific shipments. Total demand for petroleum products in the Pacific Coast area, therefore, should be normal in 1941. Withdrawals of fuel oil from storage during the coming year are expected to be 15,000,000 barrels.

Wildcat mortality in California continued to be high and will tend to rise as the potentially productive area is reduced. In contrast with previous years the discoveries and extensions during 1940 were mainly in the Los Angeles Basin.

Oil and Gas Development in Illinois in 1940

By Alfred H. Bell,* Member A.I.M.E., and George V. Cohee†

Illinois produced 146,788,000 bbl. of oil in 1940, or nearly 11.0 per cent of the total for the United States, and ranked fourth among the oil-producing states. Its production was only slightly less than that of Oklahoma, which produced 11.5 per cent of the national total. Illinois' production in 1940 represents an increase of 55 per cent over the previous year, when it amounted to 94,912,000 barrels.

The development of the Devonian limestone in the Salem and Centralia fields is largely responsible for the increase in production during 1940. Production from the Devonian limestone in these two fields was estimated to be 36,698,000 bbl., or 25 per cent of the state's total production (Table 1). The increase in production during June, when the state's daily average production attained a peak of 518,200 bbl. for the week ending June 29, was due to the Devonian production at Centralia (Fig. 1). The initial production of the best Devonian wells in the Centralia field was as high as 12,000 bbl. in 24 hr. Daily average production in Illinois for 1940 was 400,000 bbl. of oil, but actually daily production fluctuated widely during the year. At the beginning of 1940 daily production was approximately 330,000 bbl. During the first half of the year it increased irregularly to the peak in June mentioned above and as the prolific Devonian producing areas were drilled up, the state's daily production declined rapidly during July and continued to decline, although more slowly, until the end of the year, when the daily production was approximately 325,000 bbl. The daily average production per well in the new fields at the end of the year was approximately 40 bbl. (Fig. 1).

Oil from the Devonian was also produced in the Bartelso field, Clinton County, the Sandoval field, Marion County, and the Irvington field, Washington County, bringing the estimated total production from the Devonian limestone to about 26 per cent of the state's total production. The remainder was obtained largely from the Mississippian system.

About 2 per cent of the total was from Pennsylvanian and Ordovician strata. The decline in the Devonian limestone production has been so rapid that the 1941 output from this system will probably be only a small fraction of that of 1940 unless large new reserves are discovered.

The "Trenton" (Ordovician) limestone has been tested in two wells in the Centralia field and both were small oil producers at a depth of about 4000 ft. The "Trenton" also was found productive in the Salem field at a depth of 4500 ft. (Table 5). The initial production of the discovery well, which was completed shortly after the end of the year, was 130 bbl. on pump. Other wells drilled early in 1941 had initial productions averaging 172 barrels.

The outlook for 1941 is for a continuation of drilling activity in Illinois, but at a declining rate (Fig. 1, upper curve). The most active area at the end of 1940 was in the deep basin area in Wabash, Edwards, White, and Hamilton Counties.

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TABLE I.—*Oil and Gas Production in Illinois*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
1	Warrenton-Borton, *Edgar*.	1906	100	0	30,000	345	0	0	22	0	0	14	0	0
2	Westfield, *Clark, Coles*....	1904	9,000	75	*x*	*x*	*x*	0	1,627	3	26	14	311	0
3			850	75	*x*	*x*	*x*	0	186	1	0	*y*	*y*	0
4			9,000	0	*x*	*x*	*x*	0	1,448	2	0	*y*	*y*	0
5			220	0	*x*	*x*	*x*	0	13	0	0	*y*	*y*	0
6	Siggins, *Cumberland, Clark*	1906	3,580	105	*x*	*x*	*x*	0	995	0	31	0	812	0
7			3,135	55	*x*	*x*	*x*	0	854	0	*y*	0	*y*	0
8			435	15	*x*	*x*	*x*	0	90	0	*y*	0	*y*	0
9			855	105	*x*	*x*	*x*	0	192	0	*y*	0	*y*	0
10	York, *Cumberland*........	*y*	310	40	*x*	*x*	*x*	0	70	0	0	0	44	0
11	Casey, *Clark*.............	1906	1,925	55	*x*	*x*	*x*	0	533	1	0	0	489	0
12			190	15	*x*	*x*	*x*	0	41	0	0	0	*y*	0
13			400	0	*x*	*x*	*x*	0	82	0	0	0	*y*	0
14			1,525	15	*x*	*x*	*x*	0	320	1	0	0	*y*	0
15	Martinsville, *Clark*.......	1907	710	155	*x*	*x*	*x*	0	215	2	10	2	112	0
16			15	20	*x*	*x*	*x*	0	7	0	*y*	*y*	*y*	0
17			275	35	*x*	*x*	*x*	0	63	0	*y*	*y*	*y*	0
18			710	0	*x*	*x*	*x*	0	22	1	*y*	*y*	*y*	0
19			600	0	*x*	*x*	*x*	0	34	0	*y*	*y*	*y*	0
20			640	0	*x*	*x*	*x*	0	39	0	*y*	*y*	*y*	0
21			10	0	*x*	*x*	0	0	2	1	*y*	*y*	*y*	0
22	North Johnson, *Clark*.....	1907	1,320	20	*x*	*x*	*x*	*x*	485	0	0	0	433	0
23			1,115	0	*x*	*x*	*x*	*x*	296	0	0	0	*y*	0
24			160	0	*x*	*x*	*x*	*x*	32	0	0	0	*y*	0
25			820	5	*x*	*x*	*x*	*x*	177	0	0	0	*y*	0
26			215	0	*x*	*x*	0	0	44	0	0	0	*y*	0
27	South Johnson, *Clark*.....	1907	1,715	65	*x*	*x*	*x*	*x*	535	0	0	0	479	0
28			185	5	*x*	*x*	*x*	*x*	38	0	0	0	*y*	0
29			295	0	*x*	*x*	*x*	*x*	59	0	0	0	*y*	0
30			1,675	35	*x*	*x*	*x*	*x*	402	0	0	0	*y*	0
31			845	5	*x*	*x*	*x*	*x*	170	0	0	0	*y*	0
32	Bellair, *Crawford, Jasper*..	1907	1,300	5	*x*	*x*	*x*	*x*	486	0	0	15	380	0
33			1,165	0	*x*	*x*	*x*	*x*	310	0	0	*y*	*y*	0
34			315	0	*x*	*x*	*x*	*x*	65	0	0	*y*	*y*	0
35			910	0	*x*	*x*	*x*	*x*	182	0	0	*y*	*y*	0
36	Clark County Division[1]...		19,960	520	52,723,000	335,000	*x*	*y*	4,946	6	67	31	3,060	0
37	Main,[2] *Crawford*..........	1906	35,135	515	*x*	*x*	*x*	*x*	7,323	1	133	160	4,862	0
38			340	0	*x*	*x*	*x*	*x*	68	0	*y*	*y*	*y*	0
39			33,795	510	*x*	*x*	*x*	*x*	7,142	1	*y*	*y*	*y*	0
40			1,000	0	*x*	*x*	*x*	*x*	108	0	*y*	*y*	*y*	0
41	New Hebron, *Crawford*...	1909	1,350	210	*x*	*x*	*x*	*x*	297	0	28	0	146	0
42	Chapman, *Crawford*......	1914	1,045	515	*x*	*x*	*x*	*x*	193	0	7	0	61	0
43	Parker, *Crawford*.........	1907	1,310	30	*x*	*x*	*x*	*x*	256	0	2	0	219	0
44	Allison-Weger, *Crawford*..	*y*	1,075	20	*x*	*x*	*x*	*x*	147	0	0	0	65	0
45	Flat Rock,[3] *Crawford*.....	*y*	1,375	545	*x*	*x*	*x*	*x*	289	0	7	0	137	0
46	Birds, *Crawford*..........	*y*	4,370	115	*x*	*x*	*x*	*x*	684	0	11	5	449	0
47	Crawford County Division[6]		45,665	1,945	145,908,000	1,226,000	*x*	*y*	9,189	1	188	165	5,939	0
48	Lawrence, *Lawrence, Crawford*	1906	24,150	1,550	*x*	*x*	*x*	*x*	4,405	4	58	12	3,258	0
49			5,015	35	*x*	*x*	*x*	*x*	1,233	1	*y*	*y*	*y*	0
50			2,240	0	*x*	*x*	*x*	*x*	475	0	*y*	*y*	*y*	0
51			345	1,095	*x*	*x*	*x*	*x*	243	0	*y*	*y*	*y*	0
52			15,960	220	*x*	*x*	*x*	*x*	3,017	0	*y*	*y*	*y*	0

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Total of lines 2, 6, 10, 11, 15, 22, 27, 32.
[2] Includes Kibbie, Oblong, Robinson, and Hardinsville.
[3] Includes Swearingen gas.
[6] Total of lines 37, 41, 42, 43, 44, 45, 46.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.,[5] Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	0	0	*x*	*x*		*x*	*x*	Unnamed	Pen	S	Por	159	215	*x*	ML	Pen	715
2	0	311	200±	*x*		34.0	*x*	See below							D	St. Peter	3,009
3	0	*y*	*x*	*x*		30.0	*x*	Shallow gas sand	Pen	S	Por	281	376	36	D		
4	0	*y*	*x*	*x*		33.5	*x*	Westfield lime	MisL	L	Cav	334	446	*x*	D		
5	0		*x*	*x*		38.2	0.18	"Trenton"	Ord	L	Por	2,265	2,568	*x*	D		
6	0	812	*x*	*x*	RP	33.0	*x*	See below							D	Devonian	2,010
7	0	*y*	*x*	*x*		34.0	*x*	First Siggins sand	Pen	S	Por	367	465	*x*	D		
8	0	*y*	*x*	*x*		(33.6)		Second and third Siggins sand	Pen	S	Por	478	562	*x*	D		
9	0	*y*	*x*	*x*		(25.7)	*x*	Lower Siggins sand	Pen	S	Por	556	590	*x*	D		
10	0	44	*x*	*x*		(30.3)	*x*	York sand	Pen	S	Por	588	680	*x*	AM		960
11	0	489	*x*	*x*	RP	29.2	*x*	See below							AM	MisL	808
12	0	*y*	*x*	*x*		(31.9)	*x*	Upper gas sand	Pen	S	Por	263	358	*x*	AM		
13	0	*y*	*x*	*x*		(30.1)	*x*	Lower gas sand	Pen	S	Por	309	426	*x*	AM		
14	0	*y*	*x*	*x*		(33.6)	*x*	Casey sand	Pen	S	Por	444	505	*x*	AM		
15	0	112	*x*	*x*		36.8	*x*	See below							D	St. Peter	3,411
16	0	*y*	*x*	*x*		*y*	*x*	Shallow sand	Pen	S	Por	255	411	*x*	D		
17	0	*y*	*x*	*x*		*y*	*x*	Casey sand	Pen	S	Por	449	511	*x*	D		
18	0	*y*	*x*	*x*		*y*	*x*	Martinsville	MisL	L	Por	477	506	*x*	D		
19	0	*y*	*x*	*x*		(38.9)	*x*	Carper	MisL	S	Por	1,340	1,418	*x*	D		
20	0	*y*	*x*	*x*		*y*	*x*	"Niagaran"	Dev	L	Por	1,553	1,596	*x*	D		
21	0	*y*	*x*	*x*		(39.6)	*x*	"Trenton"	Ord	L	Por	2,708	2,830	*x*	D		
22	0	433	*x*	*x*		31.0	*x*	See below							AM	Mis	965
23	0	*y*	*x*	*x*		*y*	*x*	Claypool sand	Pen	S	Por	416	486	*x*	AM		
24	0	*y*	*x*	*x*		*y*	*x*	Shallow sands	Pen	S	Por	314	451	*x*	AM		
25	0	*y*	*x*	*x*		*y*	*x*	Casey sand	Pen	S	Por	465	508	*x*	AM		
26	0	*y*	*x*	*x*		*y*	*x*	Upper Partlow	Pen	S	Por	534	554	*x*	AM		
27	0	479	*x*	*x*		32.2	*x*	See below							AM	Devonian	2,030
28	0	*y*	*x*	*x*		*y*	*x*	Claypool sand	Pen	S	Por	392	549	*x*	AM		
29	0	*y*	*x*	*x*		*y*	*x*	Casey sand	Pen	S	Por	453	518	*x*	AM		
30	0	*y*	*x*	*x*		*y*	*x*	Upper Partlow	Pen	S	Por	489	570	*x*	AM		
31	0	*y*	*x*	*x*		28.5	*x*	Lower Partlow	Pen	S	Por	598	618	*x*	AM		
32	0	380	*x*	*x*	RP	33.7	*x*	See below							AM	MisL	1,471
33	0	*y*	*x*	*x*		(32.4)	*x*	"500 Ft." sand	Pen	S	Por	561	726	*x*	AM		
34	0	*y*	*x*	*x*		*y*	*x*	"800 Ft." sand	Pen	S	Por	817	907	*x*	AM		
35	0	*y*	*x*	*x*		(37.0)	*x*	"900 Ft." sand	MisU	S	Por	886	920	*x*	AM		
36	0	3,060	*x*	*x*		33.0	*x*							33±			
37	0	4,862	425±	*y*	RP	33.0	*x*	See below								"Trenton"	4,620
38	0	*y*	*x*	*x*		*y*	*x*	Shallow sand	Pen	S	Por	508	822	*x*	ML		
39	0	*y*	*x*	*x*		32.8	*x*	Robinson sand	Pen	S	Por	900	960	25±	ML	"Trenton"	4,620
40	0	*y*	*x*	*x*		*y*	*x*	Oblong	Mis	S, L	Por	1,337	1,416	*x*	A, ML	Mis	1,479
41	0	146	*x*	*x*	RP	30.1	*x*	Robinson sand	Pen	S	Por	940	975	*x*	ML	Mis	2,056
42	0	61	*x*	*x*		*y*	*x*	Robinson sand	Pen	S	Por	995	1,015	*x*	ML	Mis	2,279
43	0	219	*x*	*x*		29.5	*x*	Robinson sand	Pen	S	Por	1,000	1,025	*x*	ML	Pen	1,127
44	0	65	*x*	*x*		22.5	*x*	Robinson sand	Pen	S	Por	912	930	*x*	ML	Pen	1,041
45	0	137	*x*	*x*	RP	31.8	*x*	Robinson (Flat Rock) sand	Pen	S	Por	935	945	*x*	ML	Devonian	3,110
46	0	449	*x*	*x*	RP	31.8	*x*	Robinson sand	Pen	S	Por	930	950	*x*	ML	MisL	1,731
47	0	5,939	425±	*x*		32.3	*x*		Pen, Mis	S	Por				ML	"Trenton"	4,620
48	0	3,258	650±	*x*	RP	32.9	*x*	See below							A	St. Peter	5,190
49	0	*y*	*x*	*x*		*y*	*x*	Bridgeport sand	Pen	S	Por	800	1,000	40	A		
50	0	*y*	*x*	*x*		*y*	*x*	Buchanan	Pen	S	Por	1,250	1,265	15	A		
51	0	*y*	*x*	*x*		*y*	*x*	"Gas" sand	MisU	S	Por	1,330	1,345	15	A		
52	0	*y*	600±	*x*		*y*	*x*	Kirkwood	MisU	S	Por	1,400	1,430	30	A		

[4] Pressures in the southeastern Illinois oil fields are estimated bottom-hole pressures reported in previous Survey publications.

[5] All gravities given prior to 1936 (except those in parentheses) were from data for the year 1925 furnished by the Illinois Pipe Line Co. Gravities in parentheses are for particular samples, see Illinois State Geol. Survey *Bull.* 54, Table 3. The values have been converted from Baumé to A.P.I. gravities.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
53			4,020	200	*x*	*x*	*x*	*x*	688	3	*y*	*y*	*y*	0
54			6,950	0	*x*	*x*	*x*	*x*	958	0	*y*	*y*	*y*	0
55	St. Francisville, *Lawrence*	*y*	420	0	*x*	*x*	*x*	*x*	55	0	0	0	31	0
56	Lawrence County Division[7]		24,570	1,550	225,964,000	1,528,000	*x*	*y*	4,460	4	58	12	3,289	0
57	Allendale, *Wabash*	1912	1,680	0	4,849,000	106,000	*x*	*y*	427	6	0	0	207	0
58	Total Southeastern Fields[8]		91,855	3,970	429,474,000	3,195,345	*x*	*y*	19,044	17	313	222	12,495	0
59	Ayers gas, *Bond*	1922	0	325	0	0	194.4	13.8	19	0	0	0	0	7
60	Greenville gas, *Bond*	1910[9]	0	160	0	0	990.0	0	4	0	0	0	0	0
61	Bartelso, *Clinton*	1936	580	0	739,000	378,000	0	0	64	24	0	0	64	0
62			320	0	528,000	167,000	0	0	40	1	0	0	40	0
63			230	0	211,000	211,000	0	0	24	23	0	0	24	0
64	Carlyle, *Clinton*	1911	915	0	3,402,000	29,000	0	0	165	0	0	40	103	0
65	Frogtown, *Clinton*	1918[10]	300	0	*x*	0	0	0	12	0	0	0	0	0
66	Ava-Campbell Hill, *Jackson*	1917[11]	70	370	*x*	0	*x*	0	35	0	0	0	0	0
67	Colmar-Plymouth, *McDonough, Hancock*	1913	2,450	0	2,673,000	121,000	*x*	*y*	482	5	0	73	213	0
68	Decatur, *Macon*	1937[12]	10	0	1,000	0	0	0	2	0	2	0	0	0
69	Carlinville, *Macoupin*	1909[13]	30	50	*x*	0	*x*	0	8	0	0	0	0	0
70	Gillespie-Benld gas, *Macoupin*	1923[14]	0	80	0	0	135.8	0	4	0	0	0	0	0
71	Gillespie-Wyen, *Macoupin*	1915	40	0	*x*	0	0	0	22	0	0	12	0	0
72	Spanish Needle Creek gas, *Macoupin*	1915[15]	0	80	0	0	14.4	0	7	0	0	0	0	0
73	Staunton gas, *Macoupin*	1916[16]	0	400	0	0	1,050.0	0	18	0	0	0	0	0
74	Collinsville, *Madison*	1909[17]	40	0	850	0	0	0	6	0	0	0	0	0
75	Brown-Langewisch Kuester-Junction City, *Marion*	1910	175	0	*x*	*x*	0	0	10	0	0	0	9	0
76			60	0	*x*	*x*	0	0	6	0	0	0	5	0
77			115	0	*x*	*x*	0	0	4	0	0	0	4	0
78	Sandoval, *Marion*	1909	770	0	4,181,000	721,000	0	0	149	4	0	0	49	0
79			770	0	2,680,000	14,000	0	0	123	0	0	0	23	0
80			380	0	1,501,000	707,000	*x*	*y*	26	4	0	0	26	0
81	Wamac, *Marion, Clinton, Washington*	1921	250	0	422,000	19,000	0	0	104	0	7	0	36	0
82	Litchfield, *Montgomery*	1879[18]	100	0	22,000	0	0	0	18	0	1	0	0	0
83	Waterloo, *Monroe*	1920[19]	230	0	197,000	21,000	0	0	38	8	3	0	12	0
84	Jacksonville gas, *Morgan*	1910[20]	30	1,290	2,100	0	*x*	0	53	0	0	0	0	0
85	Pike County gas, *Pike*	1905[21]	0	8,960	0	0	*x*	0	68	0	0	0	0	0
86	Sparta, *Randolph*	1888[22]	65	100	*x*	0	*x*	0	20	1	1	0	0	0

[7] Total of lines 48 and 55.
[8] Total of lines 1, 36, 47, 56, 57.
[9] Abandoned 1923.
[10] Abandoned 1933.
[11] Abandoned 1934.
[12] Abandoned 1940.
[13] Abandoned 1925.
[14] Abandoned 1935.
[15] Abandoned 1934.
[16] Abandoned 1919.
[17] Abandoned 1921.
[18] Abandoned 1904.
[19] Abandoned 1930, revived 1939.
[20] Abandoned 1937.
[21] Abandoned 1930.
[22] Abandoned 1900.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.,[5] Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
53	0	*y*	650	*x*		*y*	*x*	Tracey	MisU	S	Por	1,560	1,580	20	A		
54	0	*y*	*x*	*x*		*y*	*x*	McClosky	MisL	L	Por	1,700	1,710	10	A		
55	0	31	600	*x*		37.3	*x*	Bethel	MisU	S	Por	1,843	1,865	22	ML	Mis	1,900
56	0	3,289	*x*	*x*												St. Peter	5,190
57	0	207	*x*	*x*	RP	35.1	*x*	Biehl sand	Pen	S	Por	1,425	1,460	20	AM	MisL	2,367
58	0	12,495															
59			335	*y*				Lindley (2d)	MisU	S	Por	940	945	5	A	Devonian	2,181
60			*x*					Lindley (1st, 2d)	MisU	S	Por	927	993	*x*	A	Devonian	2,290
61	0	64													D	Devonian	2,447
62	0	40	*x*	*x*		36.2	0.20	Carlyle	MisU	S	Por	984	1,008	24	D		
63	0	24	*x*	*x*		41.5	0.27	Devonian	Dev	L	Por	2,429	2,447	9	D		
64	0	63	*x*	*x*	RP	35.2	0.26	Carlyle	MisU	S	Por	1,035	1,055	20	A	St. Peter	4,120
65	0	0	*x*			31.9	*x*	Carlyle	MisU	S	Por	950	957	7	D	Cypress	962
66	0	0	*x*			*x*	*x*	Cypress	MisU	S	Por	780	798	18	A	Devonian	2,530
67	0	213	*x*	*x*	RP	37.6	0.38	Hoing sand	Dev	S	Por	447	468	21	A	"Trenton"	805
68	0	0	*x*			39.5	*x*	"Niagaran"	Dev	L	Por	2,020	2,076	30	N	St. Peter	2,991
69	0	0	135			27.7	*x*	Unnamed	Pen	S	Por	380	398	*x*	A	Pen	410
70	0	0	155					Unnamed	Pen	S	Por	542	555	*x*	A	Pen	575
71	0	0	*x*	*x*		30.0	*x*	Unnamed	Pen	S	Por	650	670	*x*	T	"Trenton"	2,560
72	0	0	*x*					Unnamed	Pen	S	Por	305	405	*x*	D	Pen	495
73	0	0	145					Unnamed	Pen	S	Por	461	491	*x*	A	"Trenton"	2,371
74	0	0	*x*			*x*	*x*	Devonian-Silurian	Dev-Sil	L	Por	1,305	1,400	20	ML	Silurian	1,500
75	0	9															
76	0	5	*x*	*x*		32.0	*x*	Dykstra, Wilson	Pen	S	Por	610	630	20	D	MisL	2,001
77	0	4	*x*	*x*		32.0	*x*	Cypress	MisU	S	Por	1,658	1,673	15	D	Devonian	3,344
78	0	49													D	Devonian	3,055
79	0	23	*x*	*x*		34.5	*x*	Benoist	MisU	S	Por	1,540	1,560	20±	D		
80	0	26	*x*	*x*		38.0	0.38	Devonian	Dev	L	Por	2,924	2,969	9	D		
81	0	36	*x*	*x*		30.2	*x*	Petro	Pen	S	Por	720	760	20	D	MisL	1,760
82	0	0	*x*			23.0	0.42	Unnamed	Pen	S	Por	664	674	*x*	D	Pen	681
83	0	12	*x*	*x*		30.2	0.79	"Trenton"	Ord	L	Por	410	460	50	A	"Trenton"	845
84	0	0	*x*			*x*	*x*	Gas sand	Pen, MisL	S, SL	Por	330	335	5	ML	"Trenton"	1,390
85	0	0	*x*					"Niagaran"	Sil	L	Por	265	275	10	A	St. Peter	893
86	0	0	*x*			*x*	*x*	Cypress	MisU	S	Por	850	857	7	D	MisU	985

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
87	Dupo, *St. Clair*	1928	670	0	1,275,000	182,000	0	0	263	15	0	0	64	0
88	Total for fields prior to Jan. 1, 1937[23]		98,600	15,830	442,388,950	4,666,345	2,384.6	13.8	20,615	74	327	347	13,045	7
89	Sorento, *Bond*	1938	30	0	4,000	3,000	0	0	3	2	2	0	1	0
90	Woburn, *Bond*	1940	180	0	93,000	93,000	0	0	24	24	0	0	24	0
91	Flora, *Clay*	1938	290	0	308,000	94,000	0	0	19	2	1	0	18	0
92			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
93			*y*	0	*x*	*x*	0	0	1	0	0	0	1	0
94			*y*	0	*x*	*x*	0	0	16	0	1	0	15	0
95	Iola, *Clay*	1939[24]	20	0	8,000	3,000	0	0	2	0	2	0	0	0
96	Clay City, *Clay, Wayne*	1937	8,450	0	15,778,000	3,882,000	0	0	420	41	4	0	412	0
97			*y*		*x*	*x*	0	0	3	3	0	0	3	0
98			*y*		*x*	*x*	0	0	1	1	0	0	1	0
99			*y*		*x*	*x*	0	0	1	1	0	0	1	0
100			*y*		*x*	*x*	0	0						
101			*y*		*x*	*x*	0	0	415	36	4	0	407	0
102	Hoffman, *Clinton*	1939	290	0	116,000	115,000	0	0	41	40	0	0	41	0
103			*y*		*x*	*x*	0	0	8	8	0	0	8	0
104			*y*		*x*	*x*	0	0	33	32	0	0	33	0
105	West Centralia, *Clinton*	1940	10	0	*x*	*x*	0	0	1	1	0	0	1	0
106	Centralia, *Clinton, Marion*	1937	2,850	0	16,520,000	10,597,000	0	0	898	345	9	3	874	0
107			*y*	0	*x*	*x*	0	0	22	1	0	0	22	0
108			*y*	0	*x*	*x*	0	0	557	26	9	1	535	0
109			2,200	0	9,100,000[26]	9,100,000[26]	0	0	317	316	0	1	316	0
110			20	0	*x*	*x*	0	0	2	2	0	1	1	0
111	Mattoon, *Coles*	1939[25]	20	0	9,000	9,000	0	0	2	1	0	0	1	0
112			10	0	*x*	*x*	0	0	1	0	0	0	0	0
113			10	0	9,000	9,000	0	0	1	1	0	0	1	0
114	Albion, *Edwards*	1940	630	0	955,000	955,000	0	0	59	59	0	0	59	0
115			*y*	0	*x*	*x*	0	0	3	3	0	0	3	0
116			*y*	0	*x*	*x*	0	0	10	10	0	0	10	0
117			*y*	0	*x*	*x*	0	0	46	46	0	0	46	0
118	Cowling, *Edwards*	1939	100	0	76,000	51,000	0	0	13	2	1	0	12	0
119	Grayville, *Edwards, White*	1939	80	0	95,000	66,000	0	0	8	0	3	0	5	0
120	Mason, *Effingham*	1940	10	0	9,000	9,000	0	0	1	1	0	0	1	0
121	Louden, *Fayette, Effingham*	1937	19,220	0	46,801,000	26,564,000	*y*	*y*	1,753	416	9	6	1,736	0
122			*y*		*x*	*x*	*y*	*y*	855	223	9	4	840	0
123			*y*		*x*	*x*	*y*	*y*	312	28	0	1	311	0
124			*y*		*x*	*x*	*y*	*y*	421	0	0	0	421	0
125									85	85	0	1	84	0
126									39	39	0	0	39	0
127									13	13	0	0	13	0
128									28	28	0	0	28	0
129	St. James, *Fayette*	1938	1,830	0	2,213.000	1,719,000	0	0	177	101	1	0	171	0
130			1,830	0	2,213,000	1,719,000	0	0	176	100	1	0	170	0
131									1	1	0	0	1	0
132	Thompsonville, *Franklin*	1940	210	0	71,000	71,000	0	0	16	16	0	0	16	0
133	Whittington, *Franklin*	1939	10	0	11,000	7,000	0	0	1	0	0	0	1	0
134	Junction, *Gallatin*	1939	150	0	124,000	100,000	0	0	14	8	0	0	14	0
135	Inman, *Gallatin*	1940	40	0	4,000	4,000	0	0	4	4	1	0	3	0
136			10	0	*x*	*x*	0	0	1	1	0	0	1	0
137			10	0	*x*	*x*	0	0	1	1	0	0	1	0
138			10	0	*x*	*x*	0	0	1	1	1	0	0	0
139			10	0	*x*	*x*	0	0	1	1	0	0	1	0
140	Omaha, *Gallatin*	1940	10	0	6,000	6,000	0	0	1	1	0	0	1	0
141	Belle Prairie, *Hamilton*	1940	10	0	3,000	3,000	0	0	1	1	0	0	1	0

[23] Total of lines 58 to 87 inclusive.
[24] Abandoned 1940.
[25] Abandoned 1939, revived 1940.
[26] Estimated.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Reservoir Pressure, Lb. per Sq. In.[4]: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.,[5] Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Producing Formation: Age[e]	Producing Formation: Character[f]	Producing Formation: Porosity[g]	Producing Formation: Depth, Avg. Ft.: Top Prod. Zone	Producing Formation: Depth, Avg. Ft.: Bottoms Prod. Wells	Producing Formation: Net Thickness, Avg. Ft.	Producing Formation: Structure[h]	Deepest Zone Tested to End of 1940: Name	Deepest Zone Tested to End of 1940: Depth of Hole, Ft.
87	0	64	x	x		32.7	0.70	"Trenton"	Ord	L	Por	601	651	50	A	"Trenton"	819
88	0	13,045															
89	0	1	x	x		x	x	Devonian	Dev	L	Por	1,830	1,893	5	D	Devonian	1,893
90	0	24	x	x		36.4	0.20	Bethel	MisU	S	Por	1,008	1,024	11	A	Devonian	2,454
91	0	18													D	MisL	3,100
92	0	2	x	x		x	x	Cypress	MisU	S	Por	2,594	2,614	5			
93	0	1	x	x		37.4	x	Bethel	MisU	S	Por	2,788	2,800	12			
94	0	15	x	x		37.2	0.24	McClosky	MisL	L	Por	2,965	2,978	6			
95	0	0	x	x		35.4	0.25	Aux Vases	MisU	S	Por	2,335	2,351	4	D	MisU	2,383
96	1	411			PM										A	MisL	3,197
97	0	3	x	x		x	x	Cypress	MisU	S	Por	2,603	2,608	14			
98	0	1	x	x		x	x	Bethel	MisU	S	Por	2,866	2,870	5			
99	0	1	x	x		x	x	{ Aux Vases[27]	MisU	S	Por	2,910	3,000	8			
100			x	x		x	x	{ Rosiclare	MisL	S	Por	2,970	3,000	6			
101	1	406	x	x		38.5	x	McClosky	MisL	L	Por	2,995	3,058	9			
102	0	41													D	Devonian	2,914
103	0	8	x	x		x	x	Cypress	MisU	S	Por	1,185	1,201	9			
104	0	33	x	x		32.2	0.21	Bethel	MisU	S	Por	1,319	1,324	7			
105	0	1	x	x		x	x	Bethel	MisU	S	Por	1,408	1,415	7		MisU	1,415
106	0	874			PM										A	"Trenton"	4,068
107	0	22	x	150		36.4	x	Cypress	MisU	S	Por	1,200	1,225	19			
108	0	535	250+	50		37.4	x	Bethel	MisU	S	Por	1,355	1,378	23			
109	0	316	x	400		37.4	0.38	Devonian	Dev	L	Por	2,860	2,919	8			
110	0	1	x	x		43.2	0.28	"Trenton"	Ord	L	Por	4,020	4,120	39			
111	0	1													A	St. Peter	4,908
112	0	0	x	x		44.1	0.16	Cypress	MisU	S	Por	1,835	1,919	25			
113	0	1	x	x		36.6	0.29	McClosky	MisL	L	Por	2,000	2,027	6			
114	0	59													A	Devonian	5,185
115	0	3	x	x		x	x	Bridgeport	Pen	S	Por	1,571	1,622	10			
116	0	10	x	x		34.0	x	Waltersburg	MisU	S	Por	2,365	2,373	10			
117	0	46	x	x		40.0	0.18	McClosky	MisL	L	Por	3,108	3,157	11			
118	0	12	x	x		36.6	0.23	Cypress	MisU	S	Por	2,620	2,640	12	D	MisL	3,175
119	0	5	x	x		35.8	0.31	McClosky	MisL	L	Por	3,093	3,188	6	A	MisL	3,269
120	0	1	x	x		x	x	McClosky	MisL	L	Por	2,491	2,503	12	D?	MisL	2,503
121	435	1,301			PM										A	Devonian	3,170
122	169	671	500+	260		36.6	0.25	Cypress	MisU	S	Por	1,493	1,549	25			
123	125	186	x	340		37.8	0.24	Paint Creek Stray	MisU	S	Por	1,546	1,571	17			
124	137	284	575+	350		38.5	x	Bethel	MisU	S	Por	1,540	1,561	18			
125	4	80						Cyp., Stray[27]									
126	0	39						Cyp., Beth.[27]									
127	0	13						Stray, Beth.[27]									
128	0	28						Cyp., Stray, Beth.[27]									
129	0	171													A	Devonian	3,375
130	0	170	x	x		34.4	0.31	Cypress	MisU	S	Por	1,581	1,600	16			
131	0	1						Cypress, Stray[27]									
132	0	16	x	x		37.8	0.16	McClosky	MisL	L	Por	3,121	3,136	12	A	MisL	3,136
133	0	1	x	x		37.6	0.24	McClosky, St. Louis[27]	MisL	L	Por	2,869	2,878	9	D	MisL	3,068
134	0	14	x	x		37.2	0.22	Waltersburg	MisU	S	Por	1,763	1,804	15	D	MisL	2,711
135	0	3													D	MisL	3,007
136	0	1	x	x		x	x	Palestine	MisU	S	Por	1,832	1,854	10			
137	0	1	x	x		x	x	Tar Springs	MisU	S	Por	2,082	2,090	4			
138	0	0	x	x		x	x	Rosiclare	MisL	S	Por	2,803	3,007	x			
139	0	1	x	x		x	x	McClosky	MisL	L	Por	2,730	2,742	12			
140	0	1	x	x		25.9	0.23	Palestine	MisU	S	Por	1,672	1,722	32	D	MisL	2,840
141	0	1	x	x		37.0	0.12	McClosky	MisL	L	Por	3,467	3,578	3	D?	MisL	3,578

[27] Wells producing from more than one sand.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
142	Dale, *Hamilton*	1940	550	0	329,000	329,000	0	0	25	25	0	0	25	0
143			y	0	x	x	0	0	23	23	0	0	23	0
144			y	0	x	x	0	0	2	2	0	0	2	0
145	Hoodville, *Hamilton*	1940	560	0	344,000	344,000	0	0	52	52	0	0	52	0
146			y	0	x	x	0	0	50	50	0	0	50	0
147			y	0	x	x	0	0	2	2	0	0	2	0
148	Boos, *Jasper*	1940	80	0	143,000	143,000	0	0	4	4	0	0	4	0
149	Hidalgo, *Jasper*	1940	20	0	5,000	5,000	0	0	2	2	0	0	2	0
150	North Boos, *Jasper*	1940	140	0	190,000	190,000	0	0	10	10	0	0	10	0
151	West Liberty, *Jasper*	1940	710	0	271,000	271,000	0	0	31	31	0	0	31	0
152	Cravat, *Jefferson*	1939	100	0	77,000	63,000	0	0	11	5	0	0	11	0
153	Dix, *Jefferson*	1938	1,350	0	1,582,000	717,000	0	0	65	8	0	0	65	0
154	Elk Prairie, *Jefferson*	1938[28]	10	0	700	0	0	0	1	0	1	0	0	0
155	Ina, *Jefferson*	1938	10	0	14,000	2,000	0	0	1	0	0	0	1	0
156	Marcoe, *Jefferson*	1938	10	0	12,000	3,000	0	0	2	0	0	0	1	0
157	Roaches, *Jefferson*	1938	120	0	245,000	175,000	0	0	10	1	0	0	10	0
158	Woodlawn, *Jefferson*	1940	10	0	x	x	0	0	1	1	0	0	1	0
159	Russellville Gas, *Lawrence*	1937	0	1,600	0	0	1,955.5	890.4	41	9	0	0	0	41
160			0	20	0	0	y	y	4	0	0	0	0	4
161			0	1,580	0	0	y	y	37	9	0	0	0	37
162	Patoka, *Marion*	1937	740	0	2,078,000	417,000	0	0	117	2	2	0	104	0
163			730	0	x	x	0	0	115	1	2	0	102	0
164			10	0	x	x	0	0	2	1	0	0	2	0
165	Salem, *Marion*	1938	9,060	0	122,756,000	70,136,000	y	y	2,410	829	17	5	2,386	0
166			y	0	x	x	y	y	457	34	0	0	453	0
167			y	0	x	x	y	y	149	8	0	0	149	0
168			y	0	x	x	y	y	550	158	17	1	534	0
169			y	0	x	x	y	y	8	2	0	0	8	0
170			5,000	0	27,600,000[26]	27,600,000[26]	y	y	540	533	0	4	536	0
171									471	33	0	0	471	0
172									231	57	0	0	231	0
173									2	2	0	0	2	0
174									1	1	0	0	1	0
175									1	1	0	0	1	0
176	Tonti, *Marion*	1939	350	0	3,469,000	2,560,000	0	0	49	14	1	1	48	0
177			y	0	x	x	0	0	4	0	0	0	4	0
178			y	0	x	x	0	0	10	6	0	0	10	0
179			y	0	x	x	0	0	29	2	1	1	28	0
180			21	0	x	x	0	0	6	6	0	0	6	0
181	Fairman, *Marion, Clinton*	1939	450	0	231,000	209,000	0	0	16	5	1	0	15	0
182	Raymond, *Montgomery*	1940	10	0	500	500	0	0	2	2	1	0	1	0
183	Waggoner, *Montgomery*	1940	40	0	1,000	1,000	0	0	4	4	0	0	4	0
184	Dundas, *Richland*	1939	2,160	0	2,298,000	2,062,000	0	0	88	70	0	0	88	0
185			y	0	x	x	0	0	1	1	0	0	1	0
186			y	0	x	x	0	0	87	69	0	0	87	0
187	Noble, *Richland*	1937	3,740	0	9,571,000	2,718,000	0	0	246	26	13	0	225	0
188			y	0	x	x	0	0	72	24	0	0	72	0
189			y	0	x	x	0	0	174	2	13	0	153	0
190	Olney, *Richland*	1937	520	0	962,000	209,000	0	0	37	2	2	0	35	0
191	Schnell, *Richland*	1938	40	0	150,000	22,000	0	0	4	0	0	0	4	0
192	Stewardson, *Shelby*	1939	30	0	11,000	7,000	0	0	3	2	0	0	3	0
193	Griffin, *Wabash*	1939	900	0	1,387,000	1,218,000	0	0	102	55	1	0	101	0
194			y		x	x	0	0	13	9	0	0	13	0
195			y	0	x	x	0	0	1	1	0	0	1	0
196			y	0	x	x	0	0	1	1	0	0	1	0
197			y	0	x	x	0	0	71	31	0	0	71	0

[28] Abandoned 1940.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Reservoir Pressure, Lb. per Sq. In.[4]: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.[5] Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Producing Formation: Age[e]	Producing Formation: Character[f]	Producing Formation: Porosity[g]	Producing Formation: Depth, Avg. Ft.: Top Prod. Zone	Producing Formation: Depth, Avg. Ft.: Bottoms Prod. Wells	Producing Formation: Net Thickness, Avg. Ft.	Producing Formation: Structure[h]	Deepest Zone Tested to End of 1940: Name	Deepest Zone Tested to End of 1940: Depth of Hole, Ft.
142	0	25													D	MisL	3,257
143	0	23	x	x		37.6	0.25	Cypress	MisU	S	Por	2,678	2,708	18			
144	0	2	x	x		x	x	McClosky	MisL	L	Por	3,143	3,185	16			
145	3	49													D?	MisL	3,224
146	3	47	x	x		38.0	x	Bethel	MisU	S	Por	2,952	2,975	20			
147	0	2	x	x		x	x	McClosky	MisL	L	Por	3,146	3,224	14			
148	0	4	x	x		39.6	0.26	McClosky	MisL	L	Por	2,818	2,865	8	A	MisL	2,865
149	0	2	x	x		x	x	McClosky	MisL	L	Por	2,560	2,607	8	N	Devonian	4,139
150	4	6	x	x		38.6	0.20	McClosky	MisL	L	Por	2,791	2,834	12	A	MisL	2,834
151	0	31	x	x		x	x	McClosky	MisL	L	Por	2,788	2,824	10	A	Devonian	4,584
152	0	11	x	x		35.4	0.23	Bethel	MisU	S	Por	2,066	2,076	11	D	MisL	2,356
153	0	65	495+	350	PM	38.0	0.18	Bethel	MisU	S	Por	1,948	1,959	14	A	Devonian	3,650
154	0	0	x	x		x	x	McClosky	MisL	L	Por	2,718	2,751	7	D	MisL	2,958
155	0	1	x	x		36.4	0.20	St. Louis	MisL	L	Por	3,002	3,007	5	D	MisL	3,064
156	0	1	x	x		23.2	0.54	McClosky	MisL	L	Por	2,746	2,765	11	D	MisL	3,066
157	0	10	x	x		37.0	0.22	McClosky, Rosiclare[27]	MisL	L, S	Por	2,187	2,257	22	D	MisL	2,285
158	0	1	x	x		x	x	Bethel	MisU	S	Por	1,974	1,990	16	D		
159			380+	x											A	Devonian	3,133
160			x	x				Pennsylvanian	Pen	S	Por	619	831	12			
161			380+	x				Buchanan	Pen	S	Por	1,078	1,119	10			
162	0	104													A	Devonian	2,956
163	0	102	x	x		39.5	x	Bethel	MisU	S	Por	1,424	1,440	16			
164	0	2	x	x		40.9	0.31	Rosiclare	MisL	S	Por	1,562	1,612	33			
165	74	2,312			PM										A	"Trenton"	4,618
166	0	453	272+	x		38.5	0.20	Bethel	MisU	S	Por	1,797	1,835	35			
167	1	148	335+	x		38.6	0.21	Aux Vases	MisU	S	Por	1,813	1,865	28			
168	2	532	700	56		39.0	x	McClosky	MisL	L	Por	1,975	2,048	17			
169	0	8	250+	x		39.0	x	Salem	MisL	L	Por	2,156	2,222	17			
170	43	493	1,276	381		42.1	0.28	Devonian	Dev	L	Por	3,350	3,444	30			
171	18	453						Beth., Aux Vases[27]									
172	10	221						McClosky, Salem[27]									
173	0	2						Beth., McClosky[27]									
174	0	1						Aux Vases, McClosky[27]									
175	0	1						McClosky, Devonian[27]									
176	1	47													D	Devonian	3,547
177	0	4	x	x		x	x	Bethel	MisU	S	Por	1,928	1,942	14			
178	0	10	x	x		37.0	x	Aux Vases	MisU	S	Por	2,003	2,038	26			
179	0	28	x	x		39.4	0.21	McClosky	MisL	L	Por	2,134	2,165	12			
180	1	5	x	x		x	x	Devonian	Dev	L	Por	3,490	3,505	15			
181	0	15	x	x		38.2	x	Bethel	MisU	S	Por	1,462	1,479	7	D	"Trenton"	4,100
182	0	1	x	x		33.5	x	Pennsylvanian	Pen	S	Por	580	598	18	D	Pen	598
183	0	4	x	x		x	x	Pennsylvanian	Pen	S	Por	611	625	14	D	Devonian	1,784
184	57	31													A	MisL	2,980
185	0	1	x	x		x	x	Cypress	MisU	S	Por	2,570	2,590	23			
186	57	30	1,100+	x		38.4	0.17	McClosky	MisL	L	Por	2,869	2,920	13			
187	0	225													A	MisL	3,201
188	0	72	x	x		34.6	0.27	Cypress	MisU	S	Por	2,544	2,639	17			
189	0	153	x	x		39.0	x	McClosky	MisL	L	Por	2,957	3,003	10			
190	0	35	x	x		37.2	0.19	McClosky	MisL	L	Por	3,052	3,073	9	A	MisL	3,222
191	0	4	x	x		37.0	0.19	McClosky	MisL	L	Por	3,012	3,068	6	D	MisL	3,120
192	0	3	x	x		37.8	0.18	Aux Vases	MisU	S	Por	1,942	1,969	5	D	MisU	1,969
193	0	101													A	MisL	3,058
194	0	13	x	x		38.0	x	Biehl	Pen	S	Por	1,719	1,728	11			
195	0	1	x	x		x	x	Clore	MisU	S	Por	1,811	1,823	9			
196	0	1	x	x		x	x	Tar Springs	MisU	S	Por	2,060	2,135	y			
197	0	71	x	x		38.0	x	Cypress	MisU	S	Por	2,444	2,480	15			

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells					
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
198			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
199			*y*	0	*x*	*x*	0	0	13	11	0	0	13	0
200	East Keensburg, *Wabash*	1939	20	0	*x*	*x*	0	0	2	2	0	0	2	0
201	Keensburg, *Wabash*	1939	1,120	0	2,402,000	1,619,000	0	0	160	40	3	0	157	0
202			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
203			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
204			*y*	0	*x*	*x*	0	0	4	4	0	0	4	0
205			*y*	0	*x*	*x*	0	0	152	0	3	0	149	0
206									1	1	0	0	1	0
207	Maud, *Wabash*	1940	130	0	43,000	43,000	0	0	9	9	0	0	9	0
208			*y*		*x*	*x*	0	0	1	1	0	0	1	0
209			*y*		*x*	*x*	0	0	8	8	0	0	8	0
210	Mt. Carmel, *Wabash*	1940	730	0	25,000	25,000	0	0	6	6	0	0	6	0
211			*y*		*x*	*x*	0	0	5	5	0	0	5	0
212			*y*		*x*	*x*	0	0	1	1	0	0	1	0
213	Mt. Carmel (West), *Wabash*	1939	20	0	*x*	*x*	0	0	2	0	1	0	1	0
214	Lancaster, *Wabash, Lawrence*	1940	320	0	341,000	341,000	0	0	28	28	1	0	27	0
215	Cordes, *Washington*	1939	1,430	0	1,184,000	716,000	0	0	128	33	1	1	127	0
216	Dubois, *Washington*	1939	60	0	21,000	19,000	0	0	4	3	0	1	3	0
217	Irvington, *Washington*	1940	440	0	510,000	510,000	0	0	39	39	0	0	39	0
218			*y*	0	*x*	*x*	0	0	33	33	0	0	33	0
219			*y*	0	*x*	*x*	0	0	6	6	0	0	6	0
220	McKinley, *Washington*	1940	10	0	4,000	4,000	0	0	1	1	0	0	1	0
221	Barnhill, *Wayne*	1939	870	0	1,230,000	637,000	0	0	63	22	1	0	62	0
222			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
223			*y*	0	*x*	*x*	0	0	60	19	1	0	59	0
224			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
225	Boyleston, *Wayne*	1938	1,460	0	1,527,000	1,308,000	0	0	83	58	0	0	83	0
226			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
227			*y*	0	*x*	*x*	0	0	81	56	0	0	81	0
228									1	1	0	0	1	0
229	Cisne, *Wayne*	1937	960	0	2,240,000	478,000	0	0	47	0	0	0	47	0
230			*y*		*x*	*x*	0	0	2	0	0	0	2	0
231			*y*		*x*	*x*	0	0	1	0	0	0	1	0
232			*y*		*x*	*x*	0	0	44	0	0	0	44	0
233	Enterprise, *Wayne*	1939	4,370	0	4,144,000	2,876,000	0	0	152	102	1	0	151	0
234			*y*	0	*x*	*x*	0	0	1	0	0	0	1	0
235			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
236			*y*	0	*x*	*x*	0	0	149	100	1	0	148	0
237	Goldengate, *Wayne*	1939	30	0	*x*	*x*	0	0	3	0	2	0	1	0
238	Leech Twp., *Wayne*	1938	240	0	232,000	127,000	0	0	14	5	0	0	14	0
239	Mt. Erie, *Wayne*	1938	10	0	10,000	3,000	0	0	1	0	0	0	1	0
240	North Aden, *Wayne*	1938	1,100	0	1,935,000	905,000	0	0	65	5	2	0	61	0
241	Rinard, *Wayne*	1937[29]	10	0	6,000	800	0	0	1	0	0	0	1	0
242	Roundprairie, *Wayne*	1940	10	0	*x*	*x*	0	0	1	1	0	0	1	0
243	South Mt. Erie, *Wayne*	1939	10	0	*x*	*x*	0	0	1	0	0	0	1	0
244	West Enterprise, *Wayne*	1940	360	0	105,000	105,000	0	0	13	13	0	0	13	0
245			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
246			*y*	0	*x*	*x*	0	0	12	12	0	0	12	0
247	Aden, *Wayne, Hamilton*	1938	360	0	244,000	101,000	0	0	8	3	0	0	8	0
248	Burnt Prairie, *White*	1940	400	0	146,000	146,000	0	0	18	18	0	0	18	0
249			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
250			*y*	0	*x*	*x*	0	0	16	16	0	0	16	0
251	Calvin, *White*	1939	1,360	0	606,00	601,000	0	0	117	115	0	0	117	0
252			*y*	0	*x*	*x*	0	0	7	7	0	0	7	0

[29] Abandoned 1939, revived 1940.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Reservoir Pressure, Lb. per Sq. In.[4]: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.,[5] Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Producing Formation: Age[e]	Producing Formation: Character[f]	Producing Formation: Porosity[g]	Producing Formation: Depth, Avg. Ft.: Top Prod. Zone	Producing Formation: Depth, Avg. Ft.: Bottoms Prod. Wells	Producing Formation: Net Thickness, Avg. Ft.	Producing Formation: Structure[h]	Deepest Zone Tested to End of 1940: Name	Deepest Zone Tested to End of 1940: Depth of Hole, Ft.
198	0	2	*x*	*x*		*x*	*x*	Bethel	MisU	S	Por	2,570	2,576	6			
199	0	13	*x*	*x*		37.0	0.38	McClosky	MisL	L	Por	2,793	2,881	13			
200	0	2	*x*	*x*		37.6	0.26	McClosky	MisL	L	Por	2,703	2,714	6	D	MisL	2,714
201	0	157													A	MisL	2,880
202	0	2	*x*	*x*		*x*	*x*	Biehl	Pen	S	Por	1,753	1,764	14			
203	0	1	*x*	*x*		*x*	*x*	Clore	MisU	S	Por	1,761	1,785	9			
204	0	4	*x*	*x*		*x*	*x*	Palestine	MisU	S	Por	1,819	1,835	16			
205	0	149	*x*	*x*		38.6	0.29	Cypress	MisU	S	Por	2,433	2,454	17			
206	0	1						Biehl, Cypress[27]									
207	0	9													D	MisL	2,634
208	0	1	*x*	*x*		*x*	*x*	Bethel	MisU	S	Por	2,120	2,132	12			
209	0	8	*x*	*x*		38.0	0.30	McClosky	MisL	L	Por	2,614	2,634	8			
210	0	6													A	MisL	2,411
211	0	5	*x*	*x*		*x*	*x*	Cypress	MisU	S	Por	2,033	2,053	9			
212	0	1	*x*	*x*		36.6	0.36	Rosiclare	MisL	S	Por	2,368	2,411	4			
213	0	1	*x*	*x*		*x*	*x*	Tar Springs	MisU	S	Por	2,793	2,881	15	D	MisL	2,556
214	0	27	*x*	*x*		39.8	0.28	McClosky	MisL	L	Por	2,683	2,700	9	D	MisL	2,700
215	0	127	*x*	*x*		37.4	0.19	Bethel	MisU	S	Por	1,259	1,285	17	A	MisL	1,550
216	0	3	*x*	*x*		31.0	0.26	Bethel	MisU	S	Por	1,359	1,370	11	D	MisU	1,370
217	1	38													D	Devonian	3,150
218	0	33	*x*	*x*		37.6	0.16	Bethel	MisU	S	Por	1,537	1,550	10			
219	1	5	*x*	*x*		39.0	*x*	Devonian	Dev	L	Por	3,092	3,150	5			
220	0	1	*x*	*x*		*x*	*x*	Bethel	MisU	S	Por	982	1,039	12	D	Devonian	2,567
221	0	62													A	MisL	3,523
222	0	2	*x*	*x*		*x*	*x*	{ Rosiclare[27] McClosky	MisL	S	Por	3,340	3,412	5			
223	0	59	*x*	*x*		37.6	0.17	McClosky	MisL	L	Por	3,385	3,412	11			
224	0	1	*x*	*x*		*x*	*x*	Salem	MisL	L	Por	3,792	3,855	*y*			
225	0	83													A	MisL	3,384
226	0	1	*x*	*x*		*x*	*x*	Rosiclare	MisL	S	Por	3,273	3,277	4			
227	0	81	50+	*x*		40.2	0.14	McClosky	MisL	L	Por	3,250	3,277	14			
228	0	1						Rosiclare, McClosky[27]									
229	0	47													A	St. Peter	7,207
230	0	2	*x*	*x*		38.5	*x*	Aux Vases	MisU	S	Por	2,982	3,029	13			
231	0	1	*x*	*x*		*x*	*x*	Rosiclare	MisL	S	Por	3,010	3,160	*y*			
232	0	44	75+	*x*		35.8	0.24	McClosky	MisL	L	Por	3,121	3,178	9			
233	16	135													A	MisL	3,392
234	0	1	*x*	*x*		*x*	*x*	Aux Vases	MisU	S	Por	2,929	2,957	16			
235	0	2	*x*	*x*		*x*	*x*	{ Rosiclare[27] McClosky	MisL	S	Por	3,047	3,114	2			
236	16	132	100+	*x*		*x*	*x*	McClosky	MisL	L	Por	3,049	3,114	12			
237	0	1	*x*	*x*		34.4	0.18	McClosky	MisL	L	Por	3,377	3,399	7	D	Devonian	5,645
238	0	14	*x*	*x*		39.0	0.19	McClosky	MisL	L	Por	3,413	3,453	11	D	MisL	3,485
239	0	1	*x*	*x*		39.8	0.18	McClosky	MisL	L	Por	3,080	3,092	*y*	D	MisL	3,135
240	0	61	40+	*x*		39.0	0.17	McClosky	MisL	L	Por	3,321	3,341	12	A	Devonian	5,393
241	0	1	*x*	*x*		38.5	*x*	McClosky	MisL	L	Por	3,144	3,154	5	D	MisL	3,154
242	0	1	*x*	*x*		*x*	*x*	McClosky	MisL	L	Por	3,172	3,300	3	D?	MisL	3,300
243	0	1	*x*	*x*		*x*	*x*	McClosky	MisL	L	Por	3,129	3,206	11	D	MisL	3,206
244	0	13													A	MisL	3,071
245	0	1	*x*	*x*		*x*	*x*	Aux Vases	MisU	S	Por	2,915	3,100	10			
246	0	12	*x*	*x*		*x*	*x*	McClosky	MisL	L	Por	3,018	3,071	7			
247	0	8	*x*	*x*		40.0	*x*	McClosky	MisL	L	Por	3,287	3,337	7	A	MisL	3,460
248	0	18													D	MisL	3,432
249	0	2	*x*	*x*		*x*	*x*	Rosiclare	MisL	S	Por	3,260	3,404	9			
250	0	16	*x*	*x*		37.0	0.28	McClosky	MisL	L	Por	3,425	3,432	11			
251	4	113													A	MisL	2,912
252	0	7	*x*	*x*		36.0	0.19	Tar Springs	MisU	S	Por	2,211	2,223	17			

TABLE I.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
253			*y*	0	*x*	*x*	0	0	18	18	0	0	18	0
254			*y*	0	*x*	*x*	0	0	6	6	0	0	6	0
255			*y*	0	*x*	*x*	0	0	31	30	0	0	31	0
256			*y*	0	*x*	*x*	0	0	13	13	0	0	13	0
257			*y*	0	*x*	*x*	0	0	12	11	0	0	12	0
258									1	1	0	0	1	0
259									1	1	0	0	1	0
260									23	23	0	0	23	0
261									4	4	0	0	4	0
262									1	1	0	0	1	0
263	Carmi, *White*	1940	10	0	500	500	0	0	1	1	0	0	1	0
264	Centerville, *White*	1940	50	0	49,000	49,000	0	0	3	3	0	0	3	0
265	Herald, *White*	1940	30	0	4,000	4,000	0	0	3	3	0	0	3	0
266			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
267			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
268	Iron, *White*	1940	760	0	1,111,000	1,111,000	0	0	46	46	0	1	45	0
269			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
270			*y*	0	*x*	*x*	0	0	27	27	0	1	26	0
271			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
272			*y*	0	*x*	*x*	0	0	17	17	0	0	17	0
273	Mill Shoals, *White*	1939	640	0	711,000	583,000	0	0	50	28	0	1	49	0
274			*y*	0	*x*	*x*	0	0	33	20	0	0	33	0
275			*y*	0	*x*	*x*	0	0	14	5	0	0	14	0
276									3	3	0	1	2	0
277	New Harmony, *White*	1939	1,210	0	920,000	920,000	0	0	87	76	1	1	85	0
278			*y*	0	*x*	*x*	0	0	14	4	0	0	14	0
279			*y*	0	*x*	*x*	0	0	2	2	0	0	2	0
280			*y*	0	*x*	*x*	0	0	12	12	0	0	12	0
281			*y*	0	*x*	*x*	0	0	5	5	0	0	5	0
282			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
283			*y*	0	*x*	*x*	0	0	1	1	0	0	1	0
284			*y*	0	*x*	*x*	0	0	39	38	1	1	37	0
285									2	2	0	0	2	0
286									3	3	0	0	3	0
287									2	2	0	0	2	0
288									1	1	0	0	1	0
289									1	1	0	0	1	0
290									3	3	0	0	3	0
291									1	1	0	0	1	0
292	Phillipstown, *White*	1939	80	0	61,000	52,000	0	0	6	4	0	0	6	0
293			*y*		*x*	*x*	0	0	2	1	0	0	2	0
294			*y*		*x*	*x*	0	0	4	3	0	0	4	0
295	Roland, *White*	1940	10	0	3,000	3,000	0	0	1	1	0	0	1	0
296	Stokes, *White*	1939	240	0	167,000	107,000	0	0	11	5	0	0	11	0
297	Storms, *White*	1939	1,400	30	1,548,000	1,517,000	0	0	130	113	0	0	127	3
298	Total for fields after Jan. 1, 1937[30]		76,410	1,630	255,685,000	142,122,000	1,955.5	890.4	8,095	3,006	83	20	7,901	44
299	Total for Illinois[31]		175,010	17,460	698,696,000	146,788,000	4,340.1	904.2	28,710	3,080	410	367	20,946	51

[30] Total of lines 89 to 300 inclusive.
[31] Total of lines 88 and 301.

TABLE 1.—(*Continued*)

Line Number	Oil-production Methods, End of 1940: Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.[4]: Initial	Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity, A.P.I. at 60°F.,[5] Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
253	0	18	x	x		x	x	Cypress	MisU	S	Por	2,590	2,630	18			
254	0	6	x	x		x	x	Paint Creek Stray	MisU	S	Por	2,659	2,705	15			
255	0	31	x	x		36.0	0.24	Bethel	MisU	S	Por	2,684	2,722	12			
256	3	10	x	x		x	x	Aux Vases	MisU	S	Por	2,818	2,838	27			
257	0	12	x	x		x	x	McClosky	MisL	S	Por	2,897	2,912	6			
258	0	1						Cyp., Stray[27]									
259	0	1						Tar springs,[27] Stray, Bethel									
260	0	23						Stray, Bethel[27]									
261	1	3						Cypress, Stray[27] Bethel, Aux Vases									
262	0	1						Tar Springs, Bethel[27]									
263	0	1	x	x		x	x	McClosky	MisL	L	Por	3,148	3,167	4	D?	MisL	3,167
264	0	3	x	x		38.0	x	McClosky	MisL	L	Por	3,355	3,373	4	D	MisL	3,373
265	0	3													D?	MisU	2,351
266	0	2	x	x		28.0	x	Pennsylvanian	Pen	S	Por	1,500	1,660	22			
267	0	1	x	x		35.0	x	Tar Springs	MisU	S	Por	2,326	2,351	18			
268	0	45													A	MisL	3,142
269	0	1	x	x		x	x	Tar Springs	MisU	S	Por	2,425	2,440	6			
270	0	26	x	x		37.2	0.29	Hardinsburg	MisU	S	Por	2,537	2,550	18			
271	0	1	x	x		x	x	Cypress	MisU	S	Por	2,708	2,753	16			
272	0	17	x	x		38.5	x	McClosky	MisL	L	Por	3,061	3,142	6			
273	0	49													A	MisL	3,316
274	0	33	x	x		39.8	0.14	Aux Vases	MisU	S	Por	3,221	3,290	10			
275	0	14	x	x		38.0	0.16	McClosky	MisL	L	Por	3,316	3,391	14			
276	0	2						Aux Vases, McClosky[27]									
277	4	81													A	MisL	2,919
278	0	14	820+	x		37.6	0.40	Waltersburg	MisU	S	Por	2,156	2,197	43			
279	0	2	x	x		38.0	x	Tar Springs	MisU	S	Por	2,225	2,296	20			
280	0	12	x	x		x	x	Cypress	MisU	S	Por	2,561	2,605	24			
281	0	5	x	x		x	x	Bethel	MisU	S	Por	2,684	2,751	18			
282	0	1	x	x		x	x	Aux Vases	MisU	S	Por	2,820	2,840	20			
283	0	1	x	x		x	x	Rosiclare	MisL	S	Por	2,906	2,920	14			
284	4	33	x	x		39.2	0.20	McClosky	MisL	L	Por	2,892	2,919	8			
285	0	2						Cyp., Beth.,[27] McClosky									
286	0	3						Walt., Cyp., Beth., Aux V., McClosky[27]									
287	0	2						Cyp., Beth., Aux V., McClosky[27]									
288	0	1						Tar Sp., Cyp., McClosky[27]									
289	0	1						Walt., Cyp.[27]									
290	0	3						Cyp., Beth.[27]									
291	0	1						Cyp., Beth., Aux Vases[27]									
292	0	6													A	Devonian	5,349
293	0	2	x	x		39.4	x	Aux Vases	MisU	S	Por	2,942	2,964	8			
294	0	4	x	x		38.2	0.21	McClosky	MisL	L	Por	2,955	2,961	10			
295	0	1	x	x		x	x	Tar Springs	MisU	S	Por	2,244	2,248	4	D?	MisU	2,248
296	0	11	50+	x		35.8	0.26	McClosky	MisL	L	Por	3,077	3,124	12	A	MisL	3,150
297	0	127	x	x		32.1	0.28	Waltersburg	MisU	S	Por	2,234	2,285	18	A	MisU	3.089
298	600	7,301															
299	600	20,334															

TABLE 2.—*Summary of Drilling and Initial Production in Illinois for 1940*

County	Number of Wells Drilled in 1940			Total Initial Production		Footage Drilled in 1940	
	Total Com-ple-tions	Total Producing		Oil, Bbl.	Gas, Thou-sands Cu. Ft.	Total	Producing Wells
		Oil	Gas				
Adams	1	0	0	0	0	465	0
Alexander	1	0	0	0	0	2,019	0
Bond	54	26	1	1,932	2,000	74,392	30,670
Brown	2	0	0	0	0	1,380	0
Bureau	3	0	0	0	0	2,270	0
Cass	1	0	0	0	0	1,070	0
Christian	1	0	0	0	0	1,330	0
Clark	15	5	1	51	10	24,930	7,971
Clay	37	23	0	3,066	0	111,212	69,247
Clinton	450	369	0	416,641	0	1,130,516	959,806
Coles	9	1	0	121	0	19,942	2,027
Crawford	13	1	0	12	0	31,548	2,981
Cumberland	1	0	0	0	0	710	0
DeKalb	1	0	0	0	0	520	0
DeWitt	1	0	0	0	0	1,570	0
Douglas	2	0	0	0	0	1,245	0
Edgar	10	0	0	0	0	7,090	0
Edwards	79	62	0	25,863	0	242,954	181,921
Effingham	12	3	0	488	0	25,563	5,629
Fayette	577	515	0	92,163	0	1,006,255	895,656
Ford	1	0	0	0	0	2,225	0
Franklin	20	16	0	4,138	0	62,819	50,200
Fulton	1	0	0	0	0	815	0
Gallatin	24	12	0	770	0	54,249	25,130
Greene	1	0	0	0	0	750	0
Hamilton	92	78	0	15,340	0	275,545	228,956
Hancock	2	1	0	1	0	1,057	372
Henderson	1	0	0	0	0	802	0
Henry	1	0	0	0	0	725	0
Iroquois	1	0	0	0	0	1,485	0
Jackson	5	0	0	0	0	10,285	0
Jasper	63	47	0	34,660	0	179,161	134,047
Jefferson	33	16	0	1,233	0	75,819	32,331
Jersey	3	0	0	0	0	4,265	0
Johnson	1	0	0	0	0	4,165	0
Knox	1	0	0	0	0	1,355	0
Lawrence	28	6	9	162	95,321	49,347	23,532
Logan	1	0	0	0	0	1,535	0
McDonough	9	3	0	2	0	7,737	1,381
Macon	4	0	0	0	0	9,524	0
Macoupin	9	0	0	0	0	5,394	0
Madison	7	0	0	0	0	15,120	0
Marion	952	890	0	944,925	0	2,794,599	2,636,964
Massac	2	0	0	0	0	5,365	0
Menard	1	0	0	0	0	1,063	0
Monroe	16	8	0	412	0	13,878	5,106
Montgomery	40	6	0	122	0	37,319	4,135
Peoria	1	0	0	0	0	1,011	0
Perry	8	0	0	0	0	14,866	0
Pike	4	0	0	0	0	1,571	0
Pope	2	0	0	0	0	3,090	0
Randolph	9	1	0	5	0	10,954	938
Richland	111	99	1	31,277	5,000	321,696	285,759
St. Clair	24	15	0	1,207	0	19,523	8,599
Saline	5	0	0	0	0	14,699	0
Schuyler	7	0	0	0	0	5,407	0
Scott	1	0	0	0	0	935	0
Shelby	11	2	0	57	0	23,357	4,102
Tazewell	2	0	0	0	0	1,675	0
Wabash	202	142	0	23,707	0	497,737	345,826
Washington	102	76	0	9,284	0	158,133	117,602
Wayne	265	229	0	68,179	0	855,462	728,125
White	479	412	4	77,355	70,750	1,325,101	1,133,451
Williamson	5	0	0	0	0	10,488	0
Woodford	2	0	0	0	0	3,945	0
Total	3,829	3,064	16	1,753,171	173,081	9,573,034	7,922,464

During 1940, the wells completed numbered 3829, of which 3064 were oil producers, 16 were gas producers and 749 were dry holes (Table 2). Of the total, 523 are classified as wildcat wells and of these 48 (or 9.2 per cent) were successful in obtaining production; 30 discovered new fields and 18 discovered extensions to known fields (Table 4 and Fig. 2).

The sequence of rock strata and relative positions of the producing zones are shown in Fig. 3.

The results of an investigation to ascertain the reason for the locations of as many as possible of the wildcat wells are set forth in the following table:

Reason for Drilling	Total Number	Successful	Per Cent
Geology, geophysics and geochemistry	303	45	15.0
Not based on geologic or geophysical information	170	2	1.2
Unknown	50	1	2.0
Total	523	48	9.2

Of the 523 wildcat wells, the 303 known to have been located by scientific methods were 15 per cent successful whereas the remaining 220 were only 1.3 per cent successful. The total footage of wildcat wells drilled in 1940 was 1,092,011 ft., of which a total of 121,342 ft. was drilled in successful wildcat wells.

The number of producing wells in the new fields increased from 5042 at the beginning to 7965 at the end of 1940.

There were 361 drilling operations in the state at the end of the year. As of Dec. 31, 1940, of this number 248 were in the new fields. The area proved for production in the new fields increased from 54,210 acres at the beginning of the year to 78,040 acres at the end, an increase of 23,830 acres, of which 6480 acres are in the 30 fields discovered in 1940 and the remainder, 17,350 acres, in extensions to known fields.

Economic Data

On the basis of posted prices, the total value of the oil produced in 1940 was approximately $158,746,200. The average price calculated from the available data on production and prices for the state was $1.05 per barrel to Aug. 21 and $1.15 per barrel for the remainder of the year. Posted prices for Illinois crude oil in 1940 were as shown in Table 3.

TABLE 3.—*Posted Prices for Illinois Crude in* 1940

Beginning Date	Oct. 21, 1939	May 25, 1940	Aug. 1, 1940	Aug. 21, 1940	Dec. 31, 1940
Old fields	$0.95	$0.95	$0.95	$1.00	$1.00
Central basin fields	1.05	1.05	1.05	1.15	1.15
Salem area	1.05	1.05	1.05	1.15	1.15
Griffin area	0.95	1.00	1.05	1.15	1.15

In 1940, a total of 9,573,034 ft. of hole was drilled in the state. Of this amount 7,922,464 ft. was drilled in producing wells. If an average cost of $3.00 per foot is assumed, the total investment in drilling was $28,719,102, including both producing wells and dry holes. The average depth of all wells drilled in the state in 1940 was 2500 ft., which is almost 500 ft. deeper than a year ago. This difference is accounted for in the development of deeper "pays" in proven fields and exploration in the deep basin area.

The average initial daily production of the oil wells was 573 bbl., an increase of 195 bbl. per well over last year's figure. The increase is due to the large Devonian wells in Salem and Centralia fields.

Pipe Lines and Refineries

Pipe-line construction in Illinois was less extensive in 1940 than in the previous year. The construction of crude-oil lines was principally to provide outlets for the new fields in Wabash, White and Hamilton Counties. It is estimated that the total daily capacity of the crude-oil lines in the

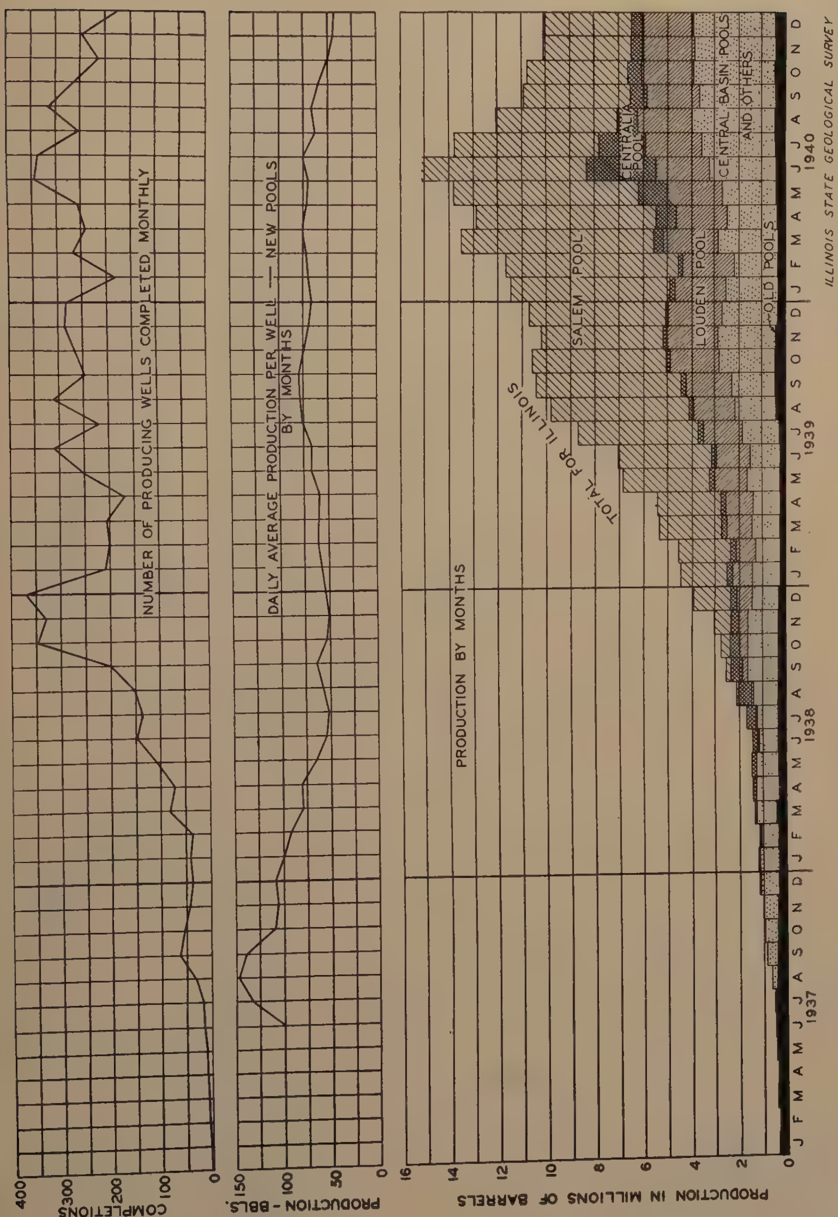
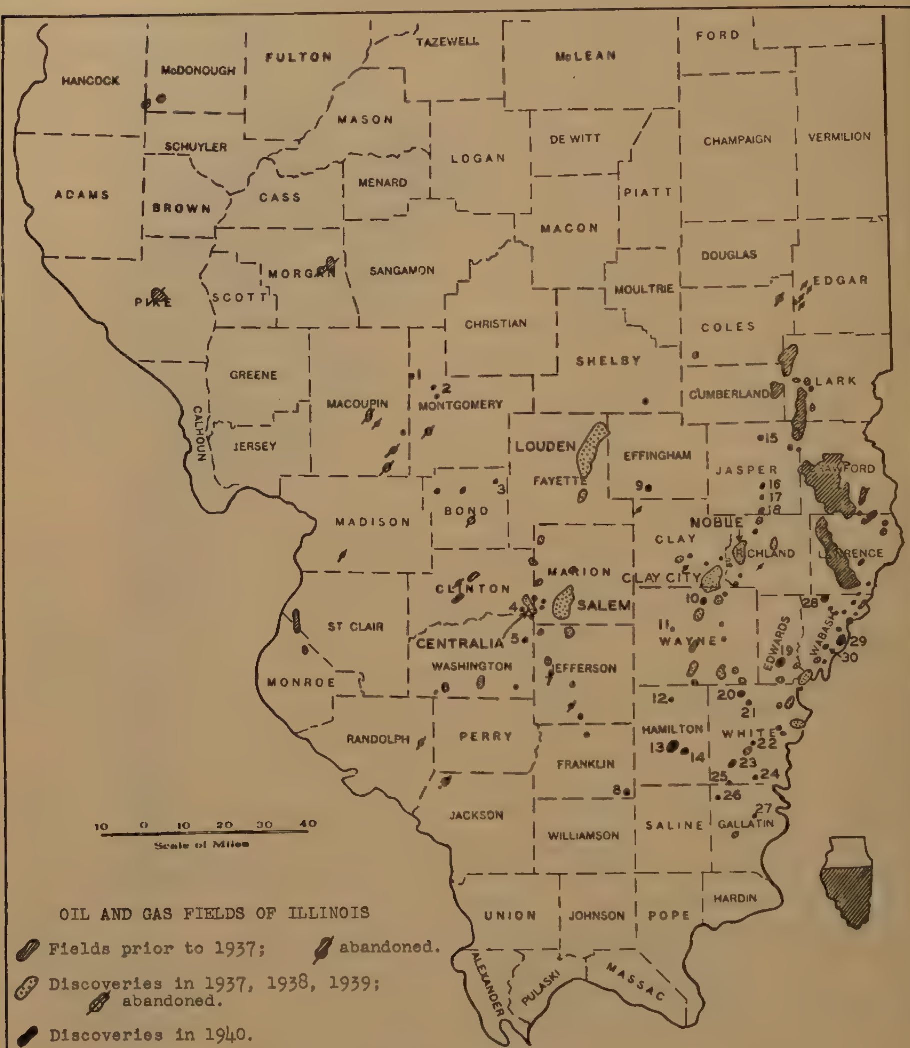


FIG. 1.—PRODUCTION, DAILY AVERAGE PRODUCTION PER WELL, NUMBER OF PRODUCING WELLS COMPLETED MONTHLY FROM 1937 TO 1940.



NEW FIELDS IN 1940

1. Waggoner; Montgomery
2. Raymond; Montgomery
3. Woburn; Bond
4. West Centralia; Clinton
5. Irvington; Washington
6. McKinley; Washington
7. Woodlawn; Jefferson
8. Thompsonville; Franklin
9. Mason; Effingham
10. West Enterprise; Wayne
11. Roundprairie; Wayne
12. Belle Prairie; Hamilton
13. Hoodville; Hamilton
14. Dale; Hamilton
15. Hidalgo; Jasper
16. North Boos; Jasper
17. Boos; Jasper
18. West Liberty; Jasper
19. Albion; Edwards
20. Burnt Prairie; White
21. Centerville; White
22. Carmi; White
23. Iron; White
24. Herald; White
25. Roland; White
26. Omaha; Gallatin
27. Inman; Gallatin
28. Lancaster; Wabash, Lawrence
29. Mt. Carmel; Wabash
30. Maud; Wabash

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FIG. 2.—OIL AND GAS FIELDS OF ILLINOIS, LISTING THE DISCOVERIES IN 1940.

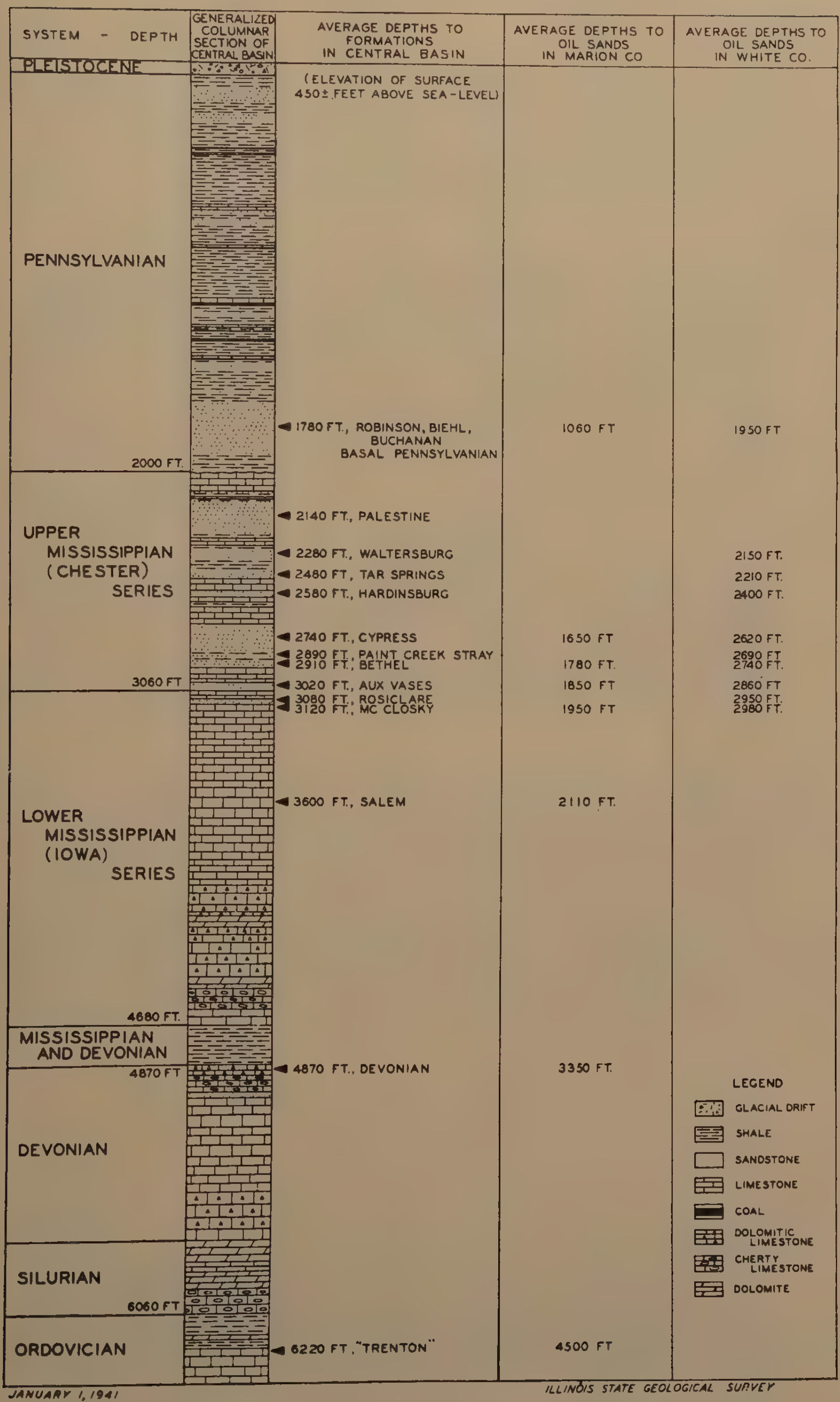

FIG. 3.—ROCK SERIES AND OIL-PRODUCING STRATA IN ILLINOIS BASIN AREA.

TABLE 4.—*Discovery Wells of New Fields and Extensions in Illinois for* 1940

Field, *County*	Company and Farm	Location	Total Depth, Ft.	Producing Formation		Initial Production, Bbl.	Date of Completion of Discovery Well	Number of Wells in Pool, 12-31-40
				Depth to Top, Ft.	Name			
Albion, *Edwards*	Noah & Morrison, Barnes No. 1	SE NE NE 24-2S-10E	3,240	3,130	McClosky limestone	132	3-26-40	55
Barn Hill, *Wayne*[1]	M. I. O. U. Corporation, French No. 1	E SE SE 4-3S-8E	3,496	3,491	McClosky limestone	248	10-29-40	63
Bartelso, *Clinton*[1]	Snell and Goldschmidt, Shaeffer No. 1	SW NE NW 33-2N-3W	2,535	2,500	Devonian limestone	4	12-3-40	64
Belle Prairie, *Hamilton*	Kingwood Oil Co., Williams No. 1	C S SE NE 3-4S-6E	3,470	3,467	McClosky limestone	50	11-19-40	1
Boos, *Jasper*	Pure Oil Co., Warren Consolidated No. 1	C E NE NW 33-6N-10E	2,847	2,822	McClosky limestone	348	3-19-40	4
Boyleston, *Wayne*[1]	H. H. Weinert, Inc., C. Bright No. 1	C N NW NE 2-2S-7E	3,340		McClosky limestone	91	11-12-40	88
Burnt Prairie, *White*	Bishop, Harrington, Busch, Griffin No. 1	SE SE SW 28-3S-9E	3,505	3,445	McClosky limestone	103	1-23-40	18
Burnt Prairie, *White*[1]	Hayes and Goad, Goad No. 1	NW SW NW 29-3S-9E	3,486	3,482	McClosky limestone	125	10-8-40	18
Calvin, *White*[1]	Patton, Reeves No. 1	NW NW SE 28-3S-14W	2,617	2,598	Cypress sandstone	138	12-10-40	118
Carmi, *White*	Mazda Oil Co., Storms No. 1	C N SW SE 26-5S-9E	3,167	3,148	McClosky limestone	65	12-10-40	1
Centerville, *White*	Sun Oil Co., C. Brown No. 1	C S SE NW 2-4S-9E	3,375	3,341	McClosky limestone	631	5-28-40	3
Dale, *Hamilton*	Kingwood Oil Co., Wilson No. 1	NW NW SE 6-6S-7E	2,695	2,662	Cypress sandstone	115	3-26-40	25
Dale, *Hamilton*[1]	Kingwood and Exchange, Prince No. 1	NW SW NW 31-5S-7E	3,257	3,126	McClosky limestone	148	12-3-40	25
Herald, *White*	Carter Oil Co., Dagley No. 1	NW NW NE 11-7S-9E	1,516	1,502	Pennsylvanian sandstone	55	9-4-40	3
Hidalgo, *Jasper*	Johnson O. & R. Co., Mendenhall No. 1	SW SW SE 17-8N-10E	2,607	2,536	McClosky limestone	175	9-4-40	2
Hoodville, *Hamilton*	Kingwood, Morris No. 1	SW SE NE 34-5S-6E	3,200	3,189	McClosky limestone	150	7-16-40	52
Inman, *Gallatin*	Colbeck et al., Duffey No. 1	NE NW NW 25-8S-9E	3,007	2,803	Rosiclare sandstone	7	4-9-40	3
Inman, *Gallatin*[1]	Colbeck, Egyptian T. & T. No. 1	SW NW NE 19-8S-10E	2,742	2,730	McClosky limestone	200	10-8-40	3
Iron, *White*	J. W. Carter et al., O. Johnson No. 1	SW NW NE 25-6S-8E	2,528	2,485	Hardinsburg sandstone	635	2-6-40	46
Iron, *White*[1]	Mercer Bros., Chapman No. 1	NE NE NW 26-6S-8E	3,077	3,055	McClosky limestone	440	7-30-40	46
Irvington, *Washington*	Gulf Refining Co., Buhl No. 1	C NW SE SW 23-1S-1W	1,538	1,519	Bethel sandstone	683	7-2-40	39
Lancaster, *Wabash*	Riddle et al., Seibert No. 1	NE NE NE 4-1N-13W	2,743	2,666	McClosky limestone	500	4-2-40	29
Lancaster, *Lawrence*[1]	United Drill. & Prod. Co., Fornhoff No. 1	SW NW SE 27-2N-13W	2,721	2,694	McClosky limestone	20	11-19-40	29
Mason, *Effingham*	Kilpatrick, Mason Community No. 1	C NE SE NW 22-6N-5E	2,503	2,491	McClosky limestone	376	12-3-40	1
Mattoon, *Coles*[1]	Carter Oil Co., J. Seaman No. 1	SE NE SW 35-12N-7E	2,027	2,002	McClosky limestone	121	6-4-40	1
Maud, *Wabash*	Lambert, Sieler No. 1	SE SE SE 27-1S-13W	2,626	2,615	McClosky limestone	192	6-18-40	9
McKinley, *Washington*	DeKalb et al., Hunleth No. 3	SW NE NW 29-3S-4W	1,186	982	Bethel sandstone	165	12-17-40	1
Mt. Carmel, *Wabash*	Delta Drilling Co., Utter No. 1	SE SE NE 17-1S-12W	2,050	2,014	Cypress sandstone	19	1-30-40	6
New Harmony, *White*[1]	Borden, McCallister No. 1	NE SE NE 7-5S-14W	2,911	2,842	Aux Vases sandstone	130	12-17-40	88
North Boos, *Jasper*	Pure Oil Co., Bergbower No. 1	C E NE SE 16-6N-10E	2,882	2,800	McClosky limestone	200	7-9-40	9
North Boos, *Jasper*[1]	Conner and Arnold, Swick No. 1	SE SE NE 17-6N-10E	2,820	2,780	McClosky limestone	746	9-10-40	9
North New Harmony, *White*[1,3]	Superior, Fitten No. 2	NE NE NE 27-4S-14W	2,296	2,225	Tar Springs sandstone	90	7-16-40	88
Omaha, *Gallatin*	Carter Oil Co., York No. 1	SE SE SW 33-7S-8E	1,722	1,672	Palestine sandstone	275	12-10-40	1
Phillipstown, *White*[1]	Neff, Garner No. 1	SW SW SW 36-4S-10E	2,971	2,953	Aux Vases sandstone	168	10-1-40	6
Raymond, *Montgomery*	Henderson Bros., Ostermeier No. 1	NW NW NW 30-10N-4W	642	618	Pennsylvanian sandstone	12	2-27-40	1
Raymond, *Montgomery*[1]	Gulf Refining Co., Moore No. 1	C N SE SE 12-10N-5W	598	580	Pennsylvanian sandstone	25	12-3-40	1
Roland, *White*	Kingwood, Martin No. 1	NW SW NE 13-7S-8E	2,248	2,244	Tar Springs sandstone	36	7-2-40	1
Roundprairie, *Wayne*	Lessing Alch, Dickey No. 1	C S SE NE 3-1S-6E	3,300	3,172	McClosky limestone	10	6-18-40	1
Storms, *White*[1]	Bates and Lichlyter, Aud No. 1	NE NE SW 27-6S-9E	2,764	2,328	Waltersburg sandstone	3[2]	1-16-40	130[4]
Thompsonville, *Franklin*	Manley Oil Co., Downen No. 1	SW SW SW 26-7S-4E	3,118	3,102	McClosky limestone	800	10-1-40	16
Tonti, *Marion*[1]	Texas Company, Chance No. 1	NW NW SW 4-2N-2E	2,235	2,154	McClosky limestone	24	10-15-40	53
Waggoner, *Montgomery*	Randall, Street No. 1	SW SW NE 31-11N-5W	625	611	Pennsylvanian sandstone	28	7-30-40	4
West Centralia, *Clinton*	Sistler, Phoenix No. 1	NW NW SW 14-1N-1W	1,415	1,408	Bethel sandstone	25	10-1-40	1
West Enterprise, *Wayne*	Pure Oil Co., Macklin No. 1	E NW NW 1-1N-7E	3,036	3,011	McClosky limestone	664	7-9-40	15
West Liberty, *Jasper*	Pure Oil Co., M. Aldrige No. 1	C E NE NW 17-5N-10E	2,850	2,790	McClosky limestone	1,422	6-4-40	32
West Liberty, *Jasper*[1]	Shieck, Payne Heirs No. 1	C S NE NE 5-5N-10E	2,808	2,770	McClosky limestone	789	11-26-40	32
Woburn, *Bond*	National Refining Co., Spindler No. 1	NW NW NW 10-6N-2W	1,021	1,009	Bethel sandstone	209	8-13-40	24
Woodlawn, *Jefferson*	Obering and Phillips, Howe No. 1	NE SW SW 25-2S-1E	1,990	1,974	Bethel sandstone	60	12-10-40	1

[1] Extension.
[2] Gas, millions cubic feet.
[3] Formerly considered a new pool; now classed as extension to New Harmony pool.
[4] Includes three gas wells.

TABLE 5.—*Important Deep Tests in Illinois in* 1940

County	Pool	Location	Company	Farm No.	Total Depth, Ft.	Deepest Formation Tested	Top, Ft.	Re-marks	Date Com-pleted
Clinton	Centralia	NW NE NE 13-1N-1W	Borton	Storer 1	4,120 4,070 PB	"Trenton"	4,012	100 bbl.	12-3-40
Clinton	Carlyle	SE NE SE 3-2N-3W	Schwarz	Schlafly 1	4,120	St. Peter	4,106	Dry	1-7-41
Clinton	Centralia	SW NE SE 12-1N-1W	Ames	Hicks 2	4,068	"Trenton"	4,018	120 bbl.	7-2-40
Clinton	Wildcat	NE NE SW 17-3N-4W	Tatum	Schrage 1	3,549	St. Peter	3,516	Dry	7-16-40
Clinton	Wildcat	SW SE SE 33-2N-4W	Trumbell	Peters 1	3,305	"Trenton"	3,210	Dry	7-23-40
Coles	Mattoon	NW NE SW 35-12N-7E	Carter	Seaman 1	4,908	St. Peter	4,689	Dry	5-14-40
Edwards	Albion	NW NE SW 19-2S-11E	Superior Oil	Green 1	5,185	Devonian	4,907	Dry	7-9-40
Edwards	Wildcat	SE SE NE 36-2S-10E	Superior Oil	Scott 1	5,196	Devonian	4,951	Dry	8-27-40
Jackson	Wildcat	SW SE SE 35-8S-5W	Trumbell	Bennett 1	2,950	"Trenton"	2,755	Dry	9-24-40
Jackson	Wildcat	SW SW SW 32-10S-3W	Manellin	Baysinger 1	2,294	St. Peter	2,288	Dry	9-20-40
Jackson	Wildcat	SE SE NE 9-8S-3W	Magnolia Petr.	Smith 1	3,893	"Trenton"	3,705	Dry	12-31-40
Jasper	West Liberty	C ½ NW NW 16-5N-10E	Pure Oil	Redman 1	4,584	Devonian	4,316	Dry	7-9-40
Marion	Sandoval	SW SE SW 4-2N-1E	Martin	Robinson 1	5,023	St. Peter	4,978	Dry	1-14-41
Marion	Salem	SW NE SW 29-2N-2E	P. Ross	Brooks 8	4,618	"Trenton"	4,505	130 bbl.	2-4-41
Marion	Fairman	C ½ NE NW 18-3N-1E	Shell Oil	Ververs 6-C	4,100	"Trenton"	3,927	Dry	10-29-40
Marion	Patoka	NE NE SW 28-4N-1E	Jones et al.	Majonnier 2	2,956	Devonian	2,886	Dry	3-5-40
Monroe	Wildcat	SE SW SE 19-1S-10W	Hoffer	Boyer 2	2,270	Cambrian	2,200	Dry	8-13-40
Randolph	Wildcat	SW NW SW 16-7S-7W	Anderson	Cassoutt 1	1,698	"Trenton"	1,555	Dry	8-13-40
Wayne	Cisne	C E ½ SE NE 27-1N-7E	Pure Oil	Billington 3	7,207	St. Peter	7,114	Dry	5-14-40
Wayne	N. Aden	SW NW SW 33-2S-7E	Rockhill	Twist A-7	5,393	Devonian	5,135	Dry	8-6-40
White	Phillipstown	C W ½ NW NW 31-4S-11E	Phillips Petr.	Garr 1	5,349	Devonian	4,885	Dry	5-14-40
White	Wildcat	NW SW NE 13-7S-8E	Kingwood	Martin 1	5,225	Devonian	4,888	Dry	7-2-40

state is approximately 550,000 bbl. Pipeline construction in Illinois during 1940 was as follows:

Crude Oil

Illinois Pipe Line Co.—16 miles 8-in., 40 miles 10-in., Enfield, Ill., White County, to Bridgeport, Ill.; 8 miles 10-in. "loop," Sandoval to Patoka.

Texas Company.—42 miles 10-in. "loop," Salem field to Heyworth; 38 miles 12-in. "loop," Heyworth to Wilmington.

Shell Oil Co., Inc.—6 miles 8-in., Centralia field to Sandoval, Ill.

Superior Oil Co.—28 miles 6-in., Albion pool to Mt. Vernon, Ind.

Sohio Pipe Line Co.—32 miles 4-in., Dale field to Mt. Vernon, Ind.

Gulf Refining Co.—10 miles 6-in. and 8-in., Centralia field to trunk line near Boulder, Ill.

Sun Oil Co.—11 miles 6-in., Centerville field to New Harmony field.

Hal R. Compton.—35 miles 4-in. outlets to fields in White, Wabash, Edwards Counties.

Gasoline

Lawrence Pipe Line Co.—55 miles 6-in. gasoline line Lawrenceville, Ill. to Mt. Vernon, Ind.

Natural Gas

Panhandle Eastern Pipeline Co.—28 miles 24-in., 50 miles 22-in., 24 miles 20-in. loops in line across central Illinois.

Natural Gas Pipe Line Co. of America.—under construction, 162 miles 20-in. Geneseo, Ill. to Milwaukee, Wis.

Early in 1940 the capacities of most refineries in the state were enlarged in order to handle the increased supply of Illinois crude oil. The Wood River Oil and Refining Co. constructed a new refinery near Wood River, Ill., with a daily capacity of 7500 bbl. This brings the total capacity of all refineries in the state up to 258,750 bbl. daily, an increase of 65,400 bbl. over the capacity a year ago.

Owing to the decline in production during the latter part of 1940, and the increased price of crude oil, eight small refineries having a capacity of 2000 bbl. or less per day, located near the new fields in southern Illinois shut down operations. At the end of the year 21 of the 29 refineries in the state were in operation.

During the year, 79.5 per cent of Illinois' crude-oil production was sent to refineries in the Central refining district (Illinois, Indiana, Kentucky, Michigan, and western Ohio), 16.0 per cent to the Appalachian refining district (eastern Ohio, western New York, western Pennsylvania, and West Virginia), and 4.5 per cent to the Atlantic seaboard. For December 1940 the runs to stills in the Central and Appalachian refining districts were 23,196,000 bbl. Of this amount, Illinois production was 44.7 per cent. Stocks of crude petroleum on hand in Illinois on Dec. 31, 1940, were 13,944,000 bbl., as compared with 12,983,000 bbl. on Dec. 31, 1939. Stocks of refined products in the Central and Appalachian refining districts compared with the previous year are as follows:

Product	Dec. 31, 1940, Bbl.	Dec. 31, 1939, Bbl.
Gasoline	19,305,000	17,465,000
Gas oil and distillate fuel	9,665,000	4,759,000
Residual fuel oil	3,248,000	3,514,000

Production of Natural Gas

Natural gas was marketed from the Ayers and Russellville gas fields and the Salem and Louden oil fields during 1940. The Ayers gas field, in Bond County, produced 13,777,300 cu. ft. of gas in 1940, which brings the total production from the field to 194,403,400 cu. ft. Production is at an average depth of 940 ft. from the Aux Vases sandstone of the Chester series. The field has a productive area of 325 acres

and the average thickness of the "pay" is 5 ft. Seven wells are producing, none of which was new in 1940. They supply gas to the city of Greenville, Illinois.

TABLE 6.—*Illinois Completions and Production Since Jan. 1, 1936*

Date	Number of Completions	Number of Producing Wells	Production,[1] Thousands Bbl. New Fields	Old Fields[2]	Total
1936	92	52			4,445
1937	449	292	2,884	4,542	7,426
1938	2,541	2,010	19,771	4,304	24,075
1939	3,675	2,970	90,908	4,004	94,912
1940:					
Jan.	234	183	11,172	328	11,500
Feb.	306	268	11,372	355	11,727
March	281	242	13,244	336	13,580
Apr.	286	254	12,564	347	12,911
May	399	342	13,427	406	13,833
June	391	338	14,793	401	15,194
July	341	251	13,381	424	13,805
Aug.	414	313	11,640	435	12,075
Sept.	333	262	10,520	405	10,925
Oct.	280	213	10,365	430	10,795
Nov.	328	245	9,702	387	10,089
Dec.	236	169	9,957	397	10,354
	3,829	3,080	142,137	4,651	146,788

[1] The figures for total production are from the U. S. Bureau of Mines; other figures are from various sources.
[2] Includes Devonian production at Sandoval and Bartelso.

Continued development during 1940 in the Russellville gas field in northeastern Lawrence County increased the productive acreage to 1600 acres, which is 680 acres more than a year ago. As of Jan. 1, 1941, there were 41 producing wells in the field. Production is from the Buchanan sand of lower Pennsylvanian age, which is encountered at a depth of 1090 ft. The average thickness of the "pay" is 10 ft. The total production for the field to the end of 1940 was 1,955,500,000 cu. ft., 890,400,000 cu. ft. being produced in 1940.

Natural-gas production for 1940 in the Louden field is estimated to be approximately 11 billion cu. ft. The average daily production in December 1940 was estimated to be 28,000,000 cu. ft. Of this amount 10,000,000 cu. ft. of gas was processed in the Carter Oil Company's two natural-gasoline plants. There is a shrinkage of 2,800,000 cu. ft. of gas in the plants, which is accounted for in the natural gasoline, butane, and propane produced and in fuel for plant operation. The total yield of natural-gasoline butane and propane is approximately 3.2 gal. per thousand cubic feet of "wet" gas. Two and one-half million cubic feet of the "dry" residue gas was injected daily into the producing sands through 63 input wells.

The town of St. Elmo, Ill., and local industries are supplied by the Monarch Gas Co. with this residue gas from the natural-gasoline plants and from a lease in the field that is producing "dry" gas from a basal Pennsylvanian sandstone, encountered at a depth of 1071 ft. The amount of the residue gas marketed during 1940 was 215,376,000 cu. ft. and the amount of gas marketed from the lease was 13,575,000 cu. ft. The Monarch Gas Co. constructed a pipe line to Brownstown, Ill., to supply the town with natural gas starting about Jan. 1, 1941.

In the Louden field during December 1940, approximately three million cubic feet of "wet" gas was used daily in field operations and the remaining 15,000,000 cu. ft. was burned in flares.

The production of natural gas with the oil in the Salem field for 1940 is estimated to be 71 billion cu. ft. The average daily production for December is estimated to be 117,000,000 cu. ft. Of this amount 52 million cu. ft. of gas was processed daily in the three natural-gasoline plants in the field. The plants are owned and operated by the Texas Company, Warren Petroleum Co., and the Sunflower Natural Gasoline Co. The total yield of natural gasoline, butane, and propane is approximately 2.6 gal. per thousand cubic feet of "wet" gas.

The city of Salem, Ill., is using residue gas from the Sunflower Natural Gasoline Company's plant and the Warren Petroleum Company's natural-gasoline plant in the Salem field. The city began to use

the gas about Oct. 1, 1940, and is taking approximately 350,000 cu. ft. daily.

A small amount of the gas produced in the field is used in field operations and the remainder of the "wet" gas and the "dry" gas not marketed or returned to the producing formation is burned in flares.

Natural-gas production in the Centralia field during 1940, which was principally from the Devonian limestone, was estimated to be approximately 10 billion cu. ft. Gas production in the field was greatest during the development of the Devonian limestone early in 1940, when the gas-oil ratio was 2000 cu. ft. per barrel. During December 1940, it was estimated that the gas production was approximately 4,000,000 cu. ft. daily. Natural gas from the Devonian limestone is used in repressuring the Cypress and Bethel sandstones on two leases in the field. In three input wells 100,000 cu. ft. of gas daily is injected in the Bethel sandstone and 60,000 cu. ft. of gas is injected daily in the Cypress sandstone through one input well.

The total volume of gas produced in the Storms field, White County, during 1940 was estimated to be approximately 22 billion cu. ft. The daily production during December was estimated to be 18,000,000 cu. ft. This is a considerable decrease from the beginning of the year, when the production was estimated to be 100,000,000 cu. ft. daily. As of Jan. 1, 1940, there were 130 producing wells in the field, three of which were strictly gas wells that were shut in. The initial production of gas produced with the oil in some wells completed in the field during 1940 was as much as 30,000,000 cu. ft. daily. As yet no gas has been marketed from the field.

Gas production in the Central basin fields in Jasper, Richland, Clay, Wayne, and northwestern White Counties has declined during 1940, particularly in the older fields such as Clay City and Noble. The total gas production during 1940 for this area is estimated to be approximately 16 billion cu. ft., with a daily production of approximately 45,000,000 cu. ft. None of the gas is marketed, but much is used in lease operations and heat treatment of the oil.

Natural gas was discovered in the W. N. Lee et al.-Thomas Sharf No. 1, C. NW¼ SW¼ SE¼ sec. 27, T.7 N., R.4 W., Bond County, on the Panama dome, which is a structure mapped on coal No. 6.[1] The gas sand, which is of lower Pennsylvanian age, was found at a depth of from 556 to 595 ft. The initial production of the well was 500,000 cu. ft. A well was drilled offsetting the Sharf No. 1, which had an estimated initial production of 1,000,000 cu. ft. More wells are to be drilled in the area in an attempt to obtain a sufficient supply of gas for marketing.

Natural Gasoline

Natural gasoline is produced at some 46 plants in the old southeastern field, at three plants in the Salem field and at two plants in the Louden field. According to the U. S. Bureau of Mines,[2] Illinois produced 21,432,000 gal. of natural gasoline in 1940. In January, the amount was 998,000 gal.; the other months ran from 1,062,000 to 3,461,000 (December). Statistics on the production of propane and butane in 1940 are not yet available.

Exploration Methods

Subsurface geology and geophysics, largely the reflection seismograph, are still the principal methods used in guiding exploration and development. Most of the seismograph activity during 1940 was in southern Illinois in White, Hamilton, Franklin, Williamson, Saline and Gallatin Counties. The number of seismograph parties operating in the state throughout the year was as follows:

[1] A. H. Bell: The Sorento Dome. Ill. Geol. Survey, Illinois Petroleum No. 6 (1926) 7, Fig. 2.

[2] G. R. Hopkins, personal communication April 3, 1941.

Date	Number of Parties	Date	Number of Parties
Jan. 1, 1940.....	7	Oct. 1, 1940...	9
Apr. 1..........	13	Jan. 1, 1941...	7
July 1..........	11		

Gravimeter exploration was conducted by at least three major companies during the year and a number of magnetometer surveys were made in the Illinois basin.

Several companies and individuals have employed geochemical and electrical exploration methods in many areas of southern Illinois. The exploration work was done principally by four companies with district representatives in the state. These methods have been used for both reconnaissance and detail studies.

Deep Tests during 1940 (Table 5)

The St. Peter sandstone was tested in the Carlyle, Mattoon, Sandoval and Cisne fields but was not found productive. In the Carter Oil Company's Seaman No. 1 well in the Mattoon field, there was a show of oil at a depth of 4690 ft. in the Glenwood sandstone overlying the St. Peter sandstone. No shows of oil were reported below the McClosky limestone in the Pure Oil Company's Stella Billington No. 3, drilled in the Cisne pool. This well, which is the deepest well drilled in the state to date, was abandoned at a depth of 7207 ft. The top of the St. Peter sandstone was encountered at a depth of 7114 ft. The sandstone was so hard and "tight" that many drilling bits were used in the thickness penetrated.

Another St. Peter test of considerable interest was the Texas Company's Tate No. 21 well in the Salem pool, which was completed early in 1941. The total depth of the well was 5655 ft., 405 ft. below the top of the St. Peter sandstone, which was reached at a depth of 5250 ft. The St. Peter was found to be 167 ft. thick. No shows were reported below the "Trenton" limestone.

The "Trenton" limestone was tested in the Fairman, Centralia and Salem fields and was found productive in the last two mentioned. Production from this formation was small in the Centralia pool but was somewhat better in the Salem pool.

The Devonian limestone was tested in Albion, West Liberty, Patoka, North Aden and Phillipstown fields, but it was not productive.

There is a revived interest in the possibility of deeper production in the old Allendale field in northeastern Wabash County. Early in 1941 a well was completed in the Bethel sandstone at a depth of 2,011 feet which had an initial production of 250 barrels on pump. The well was drilled in one of the areas recommended for deeper testing by the Illinois Geological Survey.[3] Other wells have since been completed in the Bethel sandstone in this area.

Secondary Recovery

Repressuring.—Repressuring of the Bethel and Aux Vases sandstones of the Chester series and the McClosky limestone of the Lower Mississippian system in the Salem field was continued by the Texas Company. At the end of the year about 2.5 million cu. ft. of "dry" gas daily was being injected into 32 gas-input wells. Thirteen new input wells were drilled in 1940 and eight formerly producing wells were changed to gas-input wells.

Additional gas-input wells were drilled by the Carter Oil Co. for its repressuring project in the Louden field during 1940. On Dec. 31, 1940, there were 63 input wells in operation in the Cypress, Paint Creek "Stray" and Bethel sandstones of the Chester series. The total daily amount of "dry" gas returned to the producing formations was 2.5 million cubic feet.

[3] G. F. Moulton: Deeper Production in the Allendale Oil Field, Ill. Geol. Survey, Illinois Petroleum No. 12 (1927) 16, Fig. 2.

Repressuring of the Cypress and Bethel sandstones in the northern part of the Centralia field was begun during the latter part of 1940. One input well was drilled to the Cypress sandstone on one lease and 60,000 cu. ft. of gas from the Devonian limestone is injected daily into the formation. Three input wells were drilled to the Bethel sandstone on another lease and 100,000 cu. ft. of gas is injected daily into this formation. An increase in gas volume and some increase in oil production was obtained in the wells on the lease.

Water-flooding.—Water-flooding of the McClosky limestone by the Pure Oil Co. on the B. Travis lease, sec. 33, T.3 N., R.8 E., Clay County, was discontinued early in 1940. Another project was started in March 1940 on the T. H. Tetrick lease, sec. 9, T.2 N., R.8 E., Clay County, by the same company. The experiment was conducted until October 1940, during which time 225,000 bbl. of water was injected into the McClosky limestone. Both experiments were discontinued because of the inconclusive and conflicting evidence regarding the effects upon production.

During 1940 there was little change in repressuring or water-flooding operations in the old southeastern Illinois field or in the old fields of western and southwestern Illinois.

Acknowledgments

The writers are indebted to many companies and individuals who furnished data for this report. Dr. W. H. Easton, Mr. R. B. Ralston and Mr. W. F. Meents, all of the Survey staff, assisted in the compilation of statistical data.

Oil and Gas Development in Indiana in 1940

By G. F. Fix*

Oil and gas activity reached a higher peak in Indiana during 1940 than for any like period during the past decade. Major activity, as during 1939, was in the southwestern part of the state, the Indiana portion of the Eastern Interior Coal Basin, where most of the increase was due to field drilling in previously proven areas. The amount of wildcat drilling was about the same as for 1939. No new fields of any apparent consequence were discovered during the year, with the possible exception of the College pool, in southwest Posey County. Only one well had been completed in this area at the end of the year. About 10 ft. of saturated Aux Vases sandstone was drilled in this well and the initial production was 100 bbl. of oil a day. Other discoveries during the year 1940 include: St. Thomas, in southwestern Knox County, where four McClosky wells, ranging from 100 to 300 bbl. a day initially, were completed; Buffkin, in central Posey County, with 11 oil wells and 5 gas wells completed; and new developments in two old areas—Randolph County (part of the old Trenton field) and Gentryville, northwestern Spencer County, where some oil was found many years ago.

The St. Thomas field proved disappointing, with very spotty production from the McClosky horizon of the St. Genevieve limestone at a depth of about 1875 ft. The discovery well flowed 362 bbl. a day initially. At the end of the year the field was pretty well outlined by dry holes and some inside locations were dry. The Buffkin pool also proved spotty, with production from shallow Pennsylvanian sands and from the Basal Pennsylvanian Mansfield sandstone, the latter at a depth of approximately 1175 ft., with small production from the Cypress sandstone of Chester age. Oil wells in this pool are small, ranging from 25 to 75 bbl. a day. The Randolph County area, on the east side of the Trenton gas field, showed some promise for a commercial gas field, with four completed gas wells having cumulative initial flows of about 1,200,000 cu. ft. a day. The area apparently was not depleted during the Trenton boom at the turn of the century, since casing pressures are about as high as the virgin pressure in the old field. Elsewhere the pressure has dropped as low as 5 pounds.

The Griffin field received most of the drilling during 1940, with 163 completed oil wells. This field now covers about 3200 acres on the Indiana side of the Wabash River and is not as yet completely delimited. It produced the major part of Indiana's oil during the year—a total of 3,597,000 bbl. At the end of 1940, there were 253 producing wells in Griffin. New Harmony had five completions for a total of 24. The Rockport field, in Spencer County, continued to be actively developed and had a total of 45 gas wells and 9 oil wells at the end of the year. Oil in commercial quantities had not been found in the field previous to 1940. Total gas production for the year was 394,470,000 cubic feet.

In all, 521 wells were drilled in the state during 1940, as compared to 377 for 1939. Of this number 248 were oil wells, 77 were gas wells and 196 were dry. Divided into

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TABLE 1.—*Oil and Gas Production in Indiana*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
1	Alford, *Pike*	1919	240	960	3xx,xxx	3,600
2	Blairsville, *Posey-Vanderburgh*	1933	350	0	398,xxx	34,329
3	Bristow, *Perry*	1929	180	120	61,xxx	1,442
4	Buffkin, *Posey*	1940	200	80	23,800	23,800
5	Cannelburg, *Daviess*	1925	6xx	5x	y	2,900
6	College, *Posey*	1940	40	0	3,500	3,500
7	Francisco, *Gibson*	1929	950	150	137,xxx	38,910
8	Greensburg, *Decatur*	1893	0	37,000	0	0
9	Griffin, *Gibson-Posey*[1]	1938	3,200	0	4,300,000	3,597,000
10	Harmon, *Pike*	1928	20	6xx	0	0
11	Harrison, *Harrison*	1910	0	6,6xx	0	0
12	Heusler, *Posey*	1938	250	0	444,648	276,000
13	Hudsonville, *Daviess-Pike*	1929	0	1,0xx	0	0
14	Loogootee, *Martin-Daviess*	1900	3xx	1,9xx	y	0
15	Monroe City, *Knox*	1922	4xx	0	y	1,100
16	New Harmony, *Posey*[1]	1939	300	0	509,000	466,000
17	Oakland City, *Pike*	1907	3,1xx	2xx	y	20,805
18	Oaktown, *Knox*	1930	40	1,000	58,xxx	2,xxx
19	Oatesville-Wheeling, *Pike-Gibson*	1919	1,9xx	0	y	136,510
20	Prairie Creek, *Vigo*	1937	600	0	405,100	121,999
21	Riley, *Vigo*	1906	640	0	1xx,xxx	1,825
22	Rock Hill-Grandview, *Spencer*	1928	160	0	59,xxx	5,902
23	Rockport, *Spencer*	1939	125	1,400	23,324	23,324
24	Shelburn-Graysville, *Sullivan*	1911	5,0xx	1,6xx	6,9xx,xxx	65,960
25	Siosi, *Sullivan-Vigo*	1926	750	0	2,8xx,xxx	126,279
26	St. Thomas, *Knox*	1940	60	0	28,750	28,750
27	Trenton, *Many*	1886	127,xxx	650,xxx	107,xxx,xxx	30,xxx
28	Tri-County-Somerville, *Pike-Gibson*	1925	350	80	160,xxx	12,675
29	Troy-Tell City, *Perry-Spencer*	1928	850	80	103,5xx	13,496
30	Union-Bowman, *Pike-Gibson*	1916	4,6xx	5xx	y	182,700
31	Unionville, *Monroe*	1929	0	1,4xx	0	0
32	Vanderburgh, *Vanderburgh*	1931	580	0	400,xxx	35,602
33	Veale, *Daviess*	1926	400	0	y	12,600
34	West Princeton, *Gibson*	1903	1,6xx	5xx	1,3xx,xxx	5,400
35	Miscellaneous—*Several Counties*	1940	120	0	12,700	10,700
36	Total					5,290,608

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Extends into Illinois.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Character of Oil
				During 1940		End of 1940			Number of Wells				
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	Gravity A.P.I. at 60°F., Weighted Average
1	y	6x	96	0	0	0	7	21	0	7	y	35	38
2	0	0	39	5	0	0	29	0	0	29			30.5
3	y	0	45	0	5	0	2x	0	0	2x	...		33
4	y	y	21	21	0	0	15	0	0	15			y
5	y	0	62	5	1	0	17	0	0	17			y
6	0	0	1	1	0	0	1	0	0	1			y
7	1,243.7	5.0	42	4	0	3	26	1	0	26	690	y	26–38.6
8	4,1xx.0	185.35	38x	17	1	0	0	153	1x	24x	275	100	37–39
9	0	0	253	163	2	0	251	0					
10	y	1x	28	0	0	0	0	4	0	0	450	25	
11	3,7xx	18x	120	5	1	0	0	40	0	0	175	120	
12	0	0	30	8	0	0	30	0	0	30		...	37
13	y	22.0	51	0	0	0	0	9	0	0	275	y	
14	y	7.x	58	0	2	0	0	6	0	0	250	70	
15	0	0	15	0	0	0	7	0	0	7			y
16	0	0	24	5	0	0	24	0	0	24			39
17	0	0	263	0	0	0	31	0	0	31			28
18	1,806.9	119.8	78	0	0	0	5	34	0	5	281	125	35
19	0	0	253	0	2	0	190	0	0	190			32
20	0	0	20	2	3	1	16	0	0	16			40
21	0	0	33	0	0	0	1	0	0	1			50
22	0	0	17	0	1	0	14	0	0	14			34
23	394.47	394.47	55	36	0	3	7	45	0	9	390	320	36.7
24	1,xxx	35.77	1,097	4	9	x	343	20	0	343	110	30	35
25	0	0	83	0	7	0	50	0	0	50			46
26	0	0	4	4	0	0	4	0	0	4			y
27	80x,xxx	2xx	26,5xx	15	36	y	25x	5xx	0	25x	325	y	36
28	y	y	74	0	0	0	20	0	0	20	y	y	34
29	393.x	12.2	75	1	1	0	23	4	0	23	y	45	34
30	y	y	399	0	5	3	282	y	0	279	y	y	34–36
31	0	0	17	0	0	17	0	0	0	0	250	y	
32	0	0	92	2	0	0	55	0	0	55			30.5
33	0	0	73	0	0	0	27	0	0	27			y
34	y	0	150	0	8	0	37	0	0	37			35
35	0	0	3	2	1	0	2	0	0	2			y
36		1,244.09											

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
1	Oakland City and Brown sands	MisU	S	Por	630 1,080 1,130	640 1,100 1,140	10	A	St. Louis	1,413
2	Mansfield	PenL	S	25	1,007	1,031	30	ML	Chester	1,920
3	Tar Springs, Cypress, Elwren	MisU	S	Por	280 460	320 520	20	ML	St. Genevieve	710
4	Pen (1-2), Mansfield, Cypress	Pen M(1-2) PenL, MisU	S	Por	340 633 1,130 2,370	368 739 1,179 2,401	12	A	St. Genevieve	2,865
5	L. Chester	MisU	S	Por	630	640	y	A	Chester	895
6	Aux Vases	MisU	S	Por	2,565	2,584	10	y	St. Genevieve	2,687
7	Brown, McClosky	MisU MisM	S OL, L	Por	1,340 1,600	1,380 1,650	25	A	Ordovician	4,006
8	Trenton	OrdM	L	Por	886	907	10	A	Pre-Cambrian	3,055
9	Tar Springs, Waltersburg, Elwren, Aux Vases, McClosky	MisU (1-2-3-4), MisM	S, OL	Por	2,150	2,900	y	AF	Salem	3,185
10	Mooretown	MisU	S	Por	1,100	1,125	15	A	St. Genevieve	1,321
11	New Albany	DevU	H	Fis	650	680	20	M	Trenton	1,770
12	Waltersburg, Tar Springs	MisU	S	Por	1,750 1,855	1,800 1,920	25	AF	St. Genevieve	2,643
13	Barker	MisU	S	Por	650	660	10	T	St. Louis	1,575
14	Mooretown	MisU	S	Por	532	540	10	A	Trenton	3,025
15	Mansfield, Cypress, Mooretown, Paoli	PenL(1), MisU(2-3-4)	S, L	Por	1,225 1,475 1,560	1,240 1,560	y	M	Salem	1,935
16	Waltersburg, McClosky	MisU, MisM	S, OL	Por	2,150	2,900	31	A	St. Louis	3,028
17	Oakland City, Brown	MisU	S	Por	1,085 1,107	1,112 1,126	10	A	Paoli	1,444
18	Staunton	PenL	S	Por	580 790	610 802	y	ML	St. Genevieve	1,592
19	Sample, Cypress, Mooretown, Paoli	MisU	S (1-2-3) L(4)	Por	1,250 1,270 1,340 1,725	1,270 1,290 1,360 1,740	y	A	Harrodsburg	2,050
20	Corniferous Niagara	DevM, SilM	L	Por	2,074	2,165	y	D	Silurian	2,232
21	Corniferous	DevM	L	Por	1,600	1,700	y	A	Niagaran	1,802
22	Sample	MisU	S	Por	1,310	1,320	10	MC	St. Genevieve	1,500
23	Penn, Palestine	PenL, MisU	S	Por	885	905	10	A	St. Louis	1,707
24	Penn 1-2-3-4, Harrodsburg, Niagara	PenL 1-2-3-4, MisM, SilM	S(1-2-3-4), L	Por	298-545 640-730 800-1,400 2,270	325-560 667-775 810-1,500 2,285	y	AM	Silurian	2,870
25	Corniferous, Niagara	DevM, SilM	L	Por	2,100	2,115	y	D	Trenton	3,554
26	McClosky	MisM	OL	Por	1,871	1,922	8	y	St. Genevieve	2,050
27	Trenton	Ord	L, D	Por, Fis	900	1,250	y	A	Pre-Cambrian	3,996
28	Brazil, Oakland City	PenL, MisU	S	Por	315 1,317	331 1,335	10	A	St. Genevieve	1,998
29	Sample, Cypress, Mooretown	MisU	S	Por	468 714 747 805	492 728 759 827	y	NMF	"Mis Lime"	1,708
30	Cypress, Mooretown, Paoli	MisU	S(1-2) L(3)	Por	945 1,233	950 1,250	y	A	Salem	2,205
31	Corniferous	DevM	L	Por	800	850	40	AF	Trenton	2,102
32	Mansfield	PenL	S	Por	899	911	y	ML	St. Genevieve	2,435
33	McClosky	MisM	OL	Por	1,161	1,169	10	A	Devonian	2,618
34	West Princeton	PenL	S	Por	890	920	y	A	St. Louis	3,905
35	McClosky, St. Louis	MisM	OL, L	Por	y	y	y	y	y	y
36										

TABLE 2.—*Summary of Drilling Operations in Indiana*

Important Wildcats Drilled in 1940

	County	Location Sec.	Location Twp.	Location Rge.	Total Depth, Ft.	Surface Formation
1	Adams	24	26 N	14 E	1,308	Silurian
2	Bartholomew	15	10 N	7 E	1,466	Devonian
3	Benton	27	25 N	9 W	1,750	Mississippian
4	Boone	34	19 N	2 E	1,825	Devonian
5	Clark	Grant 182	1 S	6 E	1,747	Devonian
6	Daviess	33	2 N	6 W	2,370	Pennsylvanian
7	Daviess	2	2 N	5 W	2,090	Pennsylvanian
8	Dubois	1	3 S	5 W	1,050	Pennsylvanian
9	Dubois	4	2 S	3 W	570	Pennsylvanian
10	Floyd	32	1 S	5 E	1,035	L. Mississippian
11	Floyd	4	1 S	5 E	870	L. Mississippian
12	Floyd	29	1 S	5 E	800	L. Mississippian
13	Gibson	13	2 S	9 W	1,781	Pennsylvanian
14	Gibson	15	2 S	9 W	1,384	Pennsylvanian
15	Gibson	13	2 S	12 W	2,425	Pennsylvanian
16	Gibson	2	2 S	11 W	2,208	Pennsylvanian
17	Gibson	23	2 S	9 W	3,505	Pennsylvanian
18	Gibson	17	3 S	13 W	2,828	Pennsylvanian
19	Gibson	21	3 S	12 W	2,714	Pennsylvanian
20	Gibson	29	3 S	12 W	2,810	Pennsylvanian
21	Gibson	19	3 S	11 W	2,703	Pennsylvanian
22	Gibson	12	3 S	9 W	1,768	Pennsylvanian
23	Gibson	4	2 S	10 W	1,104	Pennsylvanian
24	Gibson	17	2 S	10 W	1,515	Pennsylvanian
25	Gibson	20	1 S	11 W	1,844	Pennsylvanian
26	Gibson	10	2 S	9 W	1,675	Pennsylvanian
27	Gibson	10	4 S	10 W	2,105	Pennsylvanian
28	Gibson	31	2 S	12 W	2,802	Pennsylvanian
29	Gibson	14	2 S	12 W	2,413	Pennsylvanian
30	Gibson	20	3 S	13 W	2,906	Pennsylvanian
31	Gibson	17	3 S	11 W	2,661	Pennsylvanian
32	Gibson	25	1 S	10 W	1,803	Pennsylvanian
33	Greene	6	6 N	5 W	1,780	Pennsylvanian
34	Greene	4	7 N	5 W	3,214	Pennsylvanian
35	Greene	22	7 N	6 W	1,727	Pennsylvanian
36	Hamilton	28	18 N	3 E	1,111	Devonian
37	Hamilton	13	19 N	3 E	992	Devonian
38	Hendricks	17	15 N	2 E	1,400	Devonian
39	Huntington	6	26 N	10 E	1,033	Silurian
40	Jackson	27	5 N	3 E	570	Mississippian
41	Jasper	34	32 N	5 W	1,130	Silurian
42	Jay	29	24 N	13 E	3,404	Silurian
43	Knox	Don. 214	5 N	9 W	3,680	Pennsylvanian
44	Knox	28	5 N	7 W	2,439	Pennsylvanian
45	Knox	Don. 182	4 N	9 W	3,252	Pennsylvanian
46	Knox	2	5 N	7 W	925	Pennsylvanian
47	Knox	3	1 S	12 W	2,415	Pennsylvanian
48	Knox	Don. 171	2 N	9 W	1,935	Pennsylvanian
49	Knox	24	2 N	11 W	1,881	Pennsylvanian
50	Knox	Surv. 44	2 N	11 W	1,973	Pennsylvanian
51	Madison	8	21 N	8 E	1,383	Silurian
52	Madison	8	21 N	8 E	952	Silurian
53	Marion	15	16 N	3 E	886	Devonian
54	Marion	22	16 N	5 E	1,054	Devonian
55	Marion	26	16 N	2 E	1,266	Devonian
56	Martin	26	2 N	4 W	2,252	Pennsylvanian
57	Martin	27	5 N	3 W	1,500	Pennsylvanian
58	Martin	26	3 N	4 W	573	Pennsylvanian
59	Newton	33	32 N	8 W	880	Silurian
60	Owen	29	11 N	3 W	1,135	U. Mississippian
61	Owen	21	9 N	5 W	2,578	Pennsylvanian
62	Pike	21	1 N	7 W	1,356	Pennsylvanian
63	Pike	24	1 N	9 W	1,703	Pennsylvanian
64	Porter	28	37 N	5 W	1,105	Devonian
65	Porter	20	36 N	5 W	393	Devonian
66	Porter	28	36 N	5 W	284	Devonian
67	Posey	7	6 S	12 W	1,179	Pennsylvanian

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day		Pressure, Lb. per Sq. In.	Remarks
			Oil, U. S. Bbl.	Gas, Millions Cu. Ft.	Casing	
1	Basal Trenton	Fee				Dry hole
2	St. Peter	Haw Creek Pet. Corp.				Dry hole
3	St. Peter	A. C. Thomas				Dry hole
4	Oneota Dolomite	N. N. Smith				Dry hole
5	St. Peter	N. N. Smith				Dry hole
6	Devonian	D. L. Norris		0.750	890	Deep prod. in old pool
7	Devonian	Midwest Development				Dry hole
8	L. Mississippian	Ill.-Ind. Prod. Corp.				Dry hole
9	L. Mississippian	H. S. Myles				Dry hole
10	Trenton	L. D. Albertson et al.				Dry hole
11	Devonian	Floyd Co. Development				Dry hole
12	Devonian	Floyd Co. Development				Dry hole
13	McClosky	Sloss-Walls				Dry hole
14	L. Chester	Midwest Development	10			N. Ext. Francisco
15	McClosky	W. C. McBride, Inc.				Dry hole
16	McClosky	Major Oil of Indiana				Dry hole
17	Devonian	Midwest Development				Dry hole
18	McClosky	Cherry & Kidd				Delimit Griffin on E.
19	McClosky	Harry Fotiades	300 approx.			Discovery Fleener pool
20	St. Genevieve	Harry Fotiades				Delimit Fleener pool
21	St. Louis	A. L. Braden	145			Discovery Simpson pool
22	St. Genevieve	S. M. Kernan				Hole junked
23	Pennsylvanian	United Oil Corp.				Dry hole
24	L. Chester	United Oil Corp.				Dry hole
25	McClosky	Roberts Bros.		1.00	865	Unnamed pool
26	McClosky	Midwest Development	5			Ext. Francisco
27	McClosky	Ill.-Ind. Basin Oil Co.				Dry hole
28	St. Louis	Cherry & Kidd				Dry hole
29	McClosky	A. P. Buzzini				Dry hole
30	St. Louis	M. H. Brown et al.				Dry hole
31	McClosky	A. L. Braden	10			Owensville pool
32	McClosky	Newton Pipe Line				Dry hole
33	Devonian	F. R. Young				Dry hole
34	St. Peter	C. N. Schicker				Dry hole
35	Devonian	Midwest Development		0.431		Unnamed pool
36	Trenton	N. N. Smith				Dry hole
37	Trenton	O. H. Hammer				Dry hole
38	Trenton	Griffin Oil Co., Inc.				Dry hole
39	Trenton	M. J. Anderson				Dry hole
40	Devonian	Favorite Oil & Gas				Dry hole
41	Trenton	Clapsaddle & Harris				Dry hole
42	Pre-Cambrian	Petroleum Dev. Corp.				Dry hole
43	U. Ordovician	M. I. T. Corp.				Dry hole
44	Devonian	Richter & Cain				Dry hole
45	Silurian	Sun Oil Co.				Dry hole
46	McClosky	Mickel Bros.				Dry hole
47	McClosky	Horton-Wiggins				Dry hole
48	Salem	Newton Pipe Line				Dry hole
49	McClosky	W. C. McBride, Inc.	362			Discovery St. Thomas pool
50	McClosky	W. C. McBride, Inc.				Dry hole
51	L. Trenton	Frontier Pet. Corp.				Dry hole
52	Trenton	Frontier Pet. Corp.	2			Unnamed pool
53	Trenton	C. E. Jefferson	10			Later abandoned
54	Trenton	J. W. Adams		No gauge		Part Old Trenton field
55	L. Trenton	N. N. Smith				Dry hole
56	Silurian	Steinberger-Smith				Dry hole
57	Devonian	Harrison Development				Dry hole
58	McClosky	Norris & Gilmore				Dry hole
59	Trenton	Vaughan-Smith	5			Thayer (ext. old field)
60	Devonian	Ellis & Blowers				Dry hole
61	Trenton	Harry Schwartz et al.				Dry hole—cored to Trenton dolomite
62	McClosky	W. H. Meub				Dry hole
63	McClosky	Newton Pipe Line				Dry hole
64	Trenton	Dail Goodson				Dry hole
65	Devonian	Joe Bander				Dry hole
66	Devonian	Roung-Lowe	10	0		Unnamed pool
67	Mansfield (B. Penn)	Gulf Refining Co.	40			Discovery N. Buffkin poo

field and wildcat wells, the completions were as follows: field; oil 228, gas 70, dry,

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	County	Location Sec.	Twp.	Rge.	Total Depth, Ft.	Surface Formation
68	Posey	7	4 S	13 W	3,013	Pennsylvanian
69	Posey	30	6 S	12 W	2,810	Pennsylvanian
70	Posey	35	3 S	13 W	2,885	Pennsylvanian
71	Posey	25	7 S	15 W	2,744	Pennsylvanian
72	Posey	4	4 S	14 W	2,870	Pennsylvanian
73	Posey	26	7 S	15 W	2,883	Pennsylvanian
74	Posey	26	7 S	15 W	2,841	Pennsylvanian
75	Posey	13	7 S	15 W	2,882	Pennsylvanian
76	Posey	16	8 S	14 W	2,687	Pennsylvanian
77	Posey	17	6 S	14 W	3,005	Pennsylvanian
78	Putnam	15	14 N	5 W	2,829	Mississippian
79	Putnam	10	13 N	4 W	2,560	Mississippian
80	Ripley	14	7 N	11 E	1,598	Silurian
81	Randolph	8	21 N	12 E	1,275	Silurian
82	Spencer	31	5 S	5 W	1,210	Pennsylvanian
83	Spencer	6	7 S	7 W	1,050	Pennsylvanian
84	Spencer	22	6 S	7 W	1,010	Pennsylvanian
85	Spencer	3	7 S	6 W	1,040	Pennsylvanian
86	Spencer	4	8 S	6 W	632	Pennsylvanian
87	Spencer	4	8 S	6 W	1,075	Pennsylvanian
88	Spencer	32	6 S	7 W	1,060	Pennsylvanian
89	Spencer	12	7 S	8 W	1,065	Pennsylvanian
90	Spencer	28	4 S	4 W	2,562	Pennsylvanian
91	St. Joseph	29	38 N	4 E	574	Mississippian
92	St. Joseph	20	38 N	4 E	600	Mississippian
93	Sullivan	13	6 N	10 W	1,406	Pennsylvanian
94	Vanderburgh	33	5 S	10 W	2,435	Pennsylvanian
95	Vanderburgh	22	4 S	10 W	2,212	Pennsylvanian
96	Vanderburgh	18	7 S	11 W	1,932	Pennsylvanian
97	Vanderburgh	5	7 S	11 W	1,050	Pennsylvanian
98	Vanderburgh	8	6 S	11 W	1,255	Pennsylvanian
99	Vanderburgh	7	7 S	11 W	1,967	Pennsylvanian
100	Vermillion	9	17 N	10 W	1,509	Pennsylvanian
101	Vigo	29	13 N	8 W	1,636	Pennsylvanian
102	Vigo	19	13 N	8 W	1,644	Pennsylvanian
103	Vigo	13	11 N	9 W	1,710	Pennsylvanian
104	Whitley	3	30 N	8 E	1,375	Silurian
105	Total				186,067	

91; wildcat; oil 20, gas 7, dry 105. The wildcat oil and gas wells include field extensions as well as new discoveries.

Oil production in the state reached a 35-year high in 1940 with a total of 5,290,608 bbl. Not since the year 1906, when the declining production from the old Trenton oil field dropped below this figure, has Indiana produced a greater amount of oil in one year. Production of natural gas also increased about 30 per cent, to 1,244,000,000 cu. ft. for 1940, most of it the flush from Rockport.

Notable highlights during the year include the lifting of pipe-line proration on the older fields of the state. This proration has been in effect for the past two years, and the allowable has varied from ⅓ to ⅔ the daily potential of the well. Its removal was a boon to producers in many old fields of southwestern Indiana. Several new pipe lines were constructed to facilitate moving oil and gas from some of the newer fields, including Griffin and Rockport.

The scene of major activity in leasing and prospecting was shifting rapidly at the end of the year to northern Indiana, where the Devonian and Trenton are potential producing formations. Very little drilling was in progress at the end of the year, but some production may be discovered in this area during 1941. Leasing is

taking place at a rapid rate and many large blocks have been assembled. It is probable that in 1941 activity in Indiana will be as great or greater than in 1940.

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day		Pressure, Lb. per Sq. In.	Remarks
			Oil, U. S. Bbl.	Gas, Millions Cu. Ft.	Casing	
68	St. Genevieve	Minton-Hollingsworth				Delimit Griffin pool
69	St. Genevieve	Paul Rossi				Dry hole
70	St. Genevieve	Jarvis Bros. & Marcell				Dry hole
71	McClosky	Lewis-Armstrong-Day				Dry hole
72	McClosky	Cohen-Harris				Dry hole
73	McClosky	Carl Robinson et al.				Dry hole
74	McClosky	Carl Robinson et al.				Dry hole
75	McClosky	H. K. Riddle				Dry hole
76	McClosky	Basin Drill Co.	100			Discovery College pool
77	St. Louis	Illinois Prod. Co.				Dry hole
78	St. Peter	Stanolind Oil & Gas				Dry hole
79	L. Trenton	C. L. Williams				Dry hole
80	St. Peter	Stoll Oil Refining				Dry hole
81	Trenton	Godwin-Murray	10			Unnamed pool
82	McClosky	W. W. Damron				Dry hole
83	L. Chester	CL. Snell, Trus.	5			Unnamed pool
84	McClosky	Morgan-Keefer				Dry hole
85	McClosky	Garland Moore				Dry hole
86	Pennsylvanian	Blosser & McPherson		1.00		S. Ext. Rockport
87	L. Chester	Bright Development				Delimit Rockport
88	L. Chester	W. G. Fortner				Dry hole
89	L. Chester	Haeey Appell				Dry hole
90	Devonian	Ohio Oil Co.				Dry hole
91	Devonian	Robert Alan Crude				Dry hole
92	Devonian	Robert Alan Crude				Dry hole
93	M. Mississippian	Pearl Poole				Dry hole
94	McClosky	Vanderburgh Oil				Dry hole
95	McClosky	Burr Lambert				Dry hole
96	Upper Chester	Walter & Hawkins				Dry hole
97	Mansfield (Penn)	C. M. Stott	5			SE Ext. Blairsville
98	Mansfield	J. R. Knapp				Dry hole
99	U. Chester	Malott, Sun, Lambert				Dry hole
100	Devonian	John Stelle et al.				Dry hole
101	Devonian	H. N. Oakley				Dry hole
102	Devonian	H. N. Oakley				Dry hole
103	Devonian	E. J. Renwaldt				Dry hole
104	Trenton	Michiana Oil & Gas				Dry hole
105			1,019	3.181		

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	44	33
Number of oil wells completed during 1940	228	20 *
Number of gas wells completed during 1940	70	7 *
Number of dry holes completed during 1940	91	105

* Including some field extensions not properly wildcats.

The Oil Industry in Kansas during 1940

By W. A. Ver Wiebe*

The year 1940 was singularly unmarked by sensational developments in Kansas. Routine operations were carried on in a systematic, orderly fashion and the efforts of oil producers were concentrated on extending known fields.

In Kansas an arbitrary yardstick for wildcats has been set up. A well drilled ½ mile or more from a known pool or well is now considered a wildcat. A "rank wildcat" is one that is drilled at least 2 miles from any known producer. During 1940, rank wildcats resulted in the completion of 116 test wells, among which 16 were successful in finding new oil pools and the remaining 100 were dry holes. The ratio of successful wells to dry holes, therefore, was approximately 1:6.

During the year, 1890 wells were completed in eastern and western Kansas. This figure is somewhat lower than that given in several trade journals, because it does not include wells that were deepened or wells that were recompleted in a different geological horizon. About three fourths of these (1423) were completed as commercial oil wells (1220 in western and 203 in eastern Kansas). The commercial gas wells completed number 58 of which 10 are in eastern Kansas and 48 in western Kansas. Of the remaining completions 147 are dry holes in eastern and 262 are dry holes in western Kansas. Based on daily potential capacity, the new discoveries of the year account for a cumulative initial production of 46,000 bbl. in eastern and 2,128,000 bbl. in western Kansas. The state of Kansas attained a new peak in production, with the total of 66,245,000 bbl. for the year 1940, the number of contributing wells being 20,779. Thus the increase over 1939, when about 58 million barrels was produced, is considerable. The previous peak occurred in 1937, when 70,761,000 bbl. was marketed. In another still earlier peak, in 1917, slightly more than 45,000,000 bbl. was produced and sold. The production of gas probably reached a new peak also during 1940, with its total of 85½ billion cubic feet. Between the peak of the year 1908, when over 80 billion cubic feet was produced, and that of 1940, the production dropped to a low point of 16 billion cubic feet in the year 1921.

The number of test wells drilled was larger than in 1939; that is, 1890 compared with 1458. The first peak was reached in 1904, when 2782 wells were drilled. The number dropped off rapidly, to 368 three years later, but rose to the second and highest peak in 1918, when 4671 test wells were completed. In the period between 1904 and 1912 more gas wells were completed than oil wells. Between the high peak of completions in 1918 and somewhat lower peak of 1937, the low point was reached during 1931, with the completion of only 470 test wells.

In the number of new pools discovered, Kansas again ranks high among the states. The exact number depends somewhat upon the interpretation of a "new" area—whether it should be called a new pool or a long extension of an old pool. Unfortunately, the matter of securing the right kind of production allowable also enters into this question. Often the decision regarding a new pool cannot be made until other wells

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are drilled within the area or in the immediate vicinity. Therefore, the figures given in this report may differ from those presented in the trade journals. Table 3 lists 25 new oil pools and 2 new gas pools. Trade journals are also inclined to list as new pools the areas in which oil is discovered in a new producing horizon although in an old pool. In Table 3 such new discoveries are listed separately. During the past year, 19 discoveries of this type were made in Kansas. Two of these are listed as new horizons in pools that are classed as new pools for 1940; in other words, several producing horizons were found in some of the new pools uncovered during the year.

New Geological Information

In all cases involving new producing horizons, only the producing levels found productive elsewhere in the state were tapped. It is common, for example, to find the Arbuckle mentioned as a new horizon in a pool that previously had produced only from the Lansing-Kansas City limestones, or vice versa. Occasionally the new horizon is the Simpson (sometimes called Wilcox) or possibly another porous zone in the Pennsylvanian system.

Two new producing levels that deserve some comment are the Wabaunsee lime and the Wabaunsee sand. These two zones were named by the Nomenclature Committee to include any part of the Wabaunsee group that may be found productive now or in the future.

Most Active Pools

The most active pools during the year 1940 were the Stoltenberg pool, Ellsworth County; the Bemis pool and the Burnett pool, Ellis County; the Bornholdt pool, McPherson County; The Hall-Gurney pool, Russell County; the Laton pool, Rooks County; the Trapp pool, Russell County, and the Silica pool, Barton County.

Important extensions were also made to other pools in various parts of the state. In the northeastern part of Barton County much drilling in and near the Prusa and the Krier pools resulted in the addition of many wells, one new pool (Prusa Southeast) and three new producing horizons. In the Krier area, new producing zones were found at the level of the Topeka limestone, within the Lansing-Kansas City limestones, and in the Arbuckle dolomite. Thus, this township now boasts production in six horizons, including the Shawnee, Topeka, Lansing-Kansas City, Sooy, Arbuckle and Lamotte. In other parts of the county, wildcat drilling was successful in finding three new oil pools, which have been named the Bird, Hammer and Wondra pools. The unflagging drilling campaign within and around the large Silica pool produced two important extensions, greatly increasing the size of this phenomenal pool. According to the Kansas Nomenclature Committee, the Silica pool now includes the Silica South, Ellinwood, Ellinwood West, Clawson, Marchand, Marchand West and Wolf pools. It now has 710 wells, as compared with 624 wells at the close of 1939.

In Ellis County the Bemis pool (which had been joined to the old Shutts pool in 1939) continued in the limelight. The number of wells at the close of 1940 was one third larger than at the close of the previous year. The sensational Burnett pool doubled the number of producing wells. This statement can also be made of the Blue Hill and the Koblitz pools, although both of these are much smaller than the Burnett pool. Important additions or extensions were made to the Marshall and to the Walters pool. Two new pools were added to the Ellis County list during 1940. They have been named the Bemis-Shutts West and the Hartsook pool. Both produce oil from the Arbuckle dolomite.

In Ellsworth County, a number of wildcats drilled to the northwest and to the

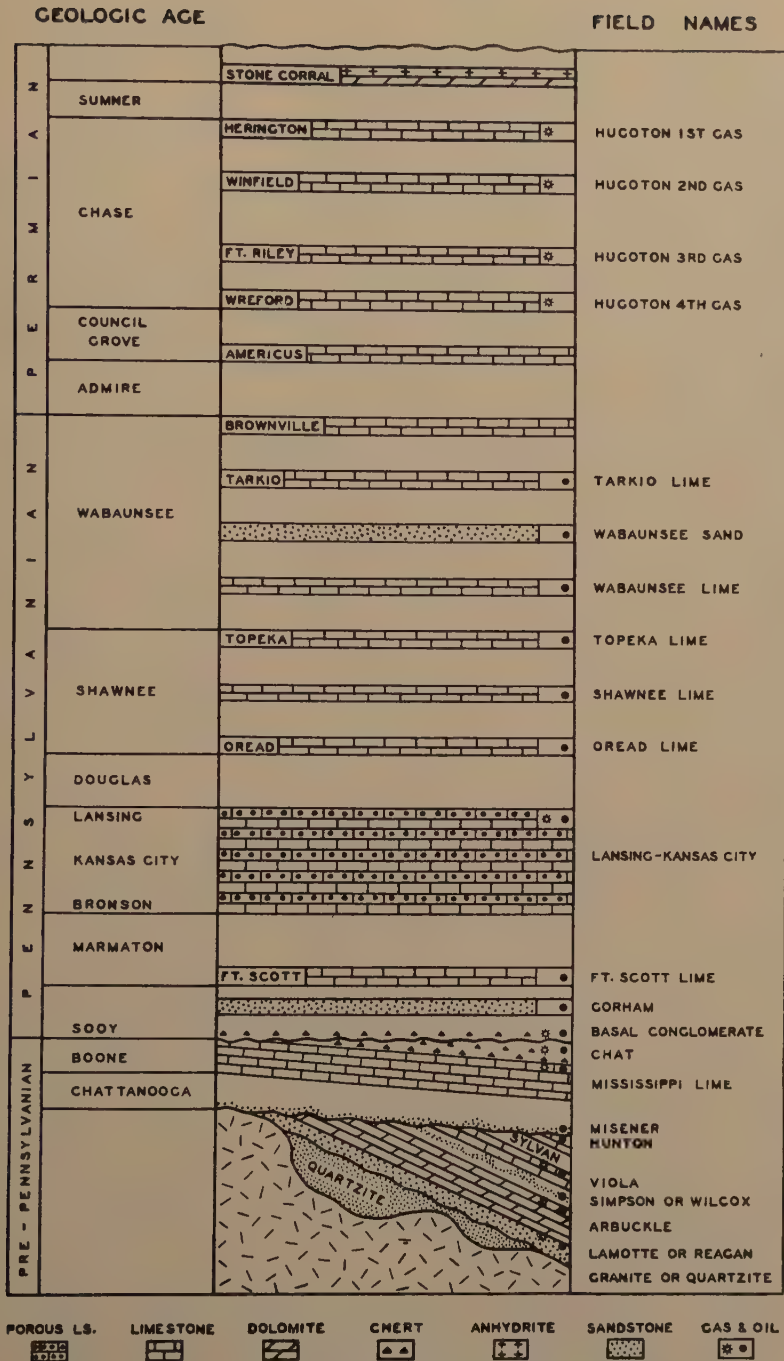

FIG. 1.—PRODUCING HORIZONS IN WESTERN KANSAS.
Data prepared by the author; drawing by L. G. Pope.

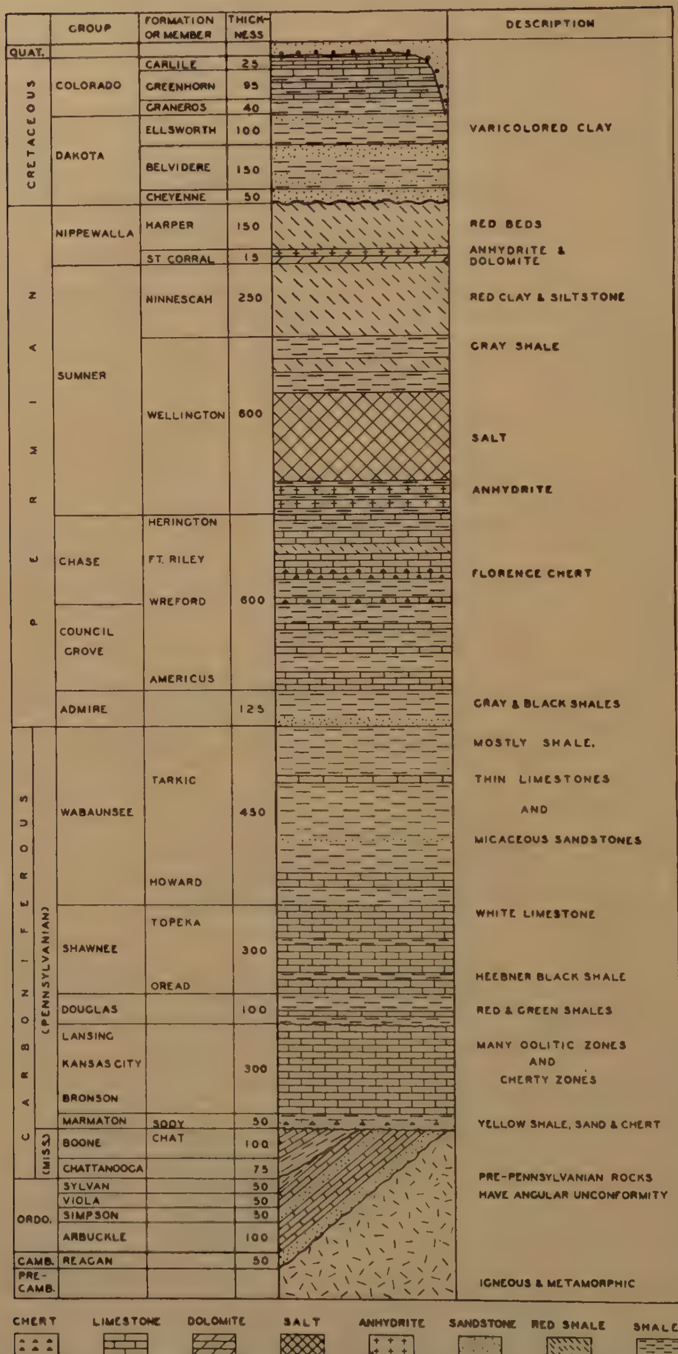

FIG. 2.—TYPICAL SEQUENCE OF ROCKS IN WESTERN KANSAS, ELLSWORTH COUNTY.

TABLE I.—*Producing Oil Fields in Kansas*

Field and Location	Discovery Date	Area, Acres	Production, Bbl. In 1940	Production, Bbl. Cumulative	Number Wells Producing	Producing Horizon Name	To Top, Ft.	Thickness, Ft.	Character
Barber County			125,991	427,920	19				
Lake City, 7-31-13W	July 1937	160	14,665	44,150	1	Viola	4,435	5	Lime
					1	Arbuckle	4,607	4	Dolomite
Medicine Lodge, 13-33-13W	March 1937	80	14,181	43,000	2	Misener	4,845	2	Lime
Whelan, 32-31-11W	Aug. 1934	640	97,145	340,770	15	Chat	4,355	29	Insoluble residue
Barton County			11,647,511	42,281,621	1,162				
Ainsworth, 26-16-13W	Dec. 1936	5,000	479,948	1,670,300	1	Oread	2,925	4	Lime
					58	Arbuckle	3,390	5	Dolomite
Albert, 30-18-15W	Jan. 1935	1,200	87,000	542,500	14	Reagan	3,601	15	Sandstone
Beaver, 16-16-12W	Dec. 1934	1,000	180,474	848,100	3	Oread	2,900	6	Lime
					20	Arbuckle	3,348	3	Dolomite
					1	Reagan	3,335	6	Sandstone
Beaver North, 4-16-12W	Oct. 1937	160	25,700	183,650	3	Arbuckle	3,316	10	Dolomite
Bird, 33-18-15W	Apr. 1940	40	2,900	2,900	1	Lamotte			Sandstone
Bloomer, 36-17-11W	Feb. 1936		3,262,294	6,711,420	32	Lans. K. C.	3,044	10	Lime
					1	Sooy	3,310		Conglomerate
					166	Arbuckle	3,257	24	Dolomite
Davidson, 4-16-11W	March 1928	80	9,286	46,500	1	Sooy	3,317	21	Conglomerate
					1	Arbuckle	3,314	26	Dolomite
Eberhardt, 14-19-11W	June 1935	160	22,420	154,300	4	Arbuckle	3,311	49	Dolomite
Ellinwood North, 33-19-11W	July 1937	80	6,131	38,500	2	Arbuckle	3,328	22	Dolomite
Feist, 29-18-11W	March 1936	40	4,591	46,026	1	Arbuckle	3,430	3	Dolomite
Feltes, 14-16-12	Nov. 1939	160	60,225	60,225	1	Sooy	3,342	2	Conglomerate
					6	Arbuckle	3,350	4	Dolomite
Hagan, 20-20-11W	Dec. 1938	40	7,230	15,330	1	Arbuckle	3,323	7	Dolomite
Hammer, 35-19-12W	Aug. 1940	40	3,450	3,450	1	Arbuckle	3,348	22	Dolomite
Harzman, 33-16-11W	Oct. 1939	40	2,045	2,400	1	Lans. K. C.	3,124	8	Lime
Heiser, 16-19-14W	Aug. 1935	40	3,370	18,900	1	Lans. K. C.	3,228	25	Lime
Hiss, 31-20-13W	Feb. 1936	160	32,002	244,800	4	Lans. K. C.	3,270	20	Lime
Hoisington, 21-17-13W	Jan. 1938	160	30,265	56,900	1	Lans. K. C.	3,222	5	Lime
					2	Arbuckle	3,440	12	Dolomite
Kraft, 10-17-11W	March 1937		341,482	956,000	55	Arbuckle	3,281	8	Dolomite
Krier, 30-16-11W	Oct. 1939		80,275	84,000	2	Topeka	2,845		Limestone
					1	Shawnee	2,885		Limestone
					1	Lans. K. C.	3,030		Limestone
					7	Sooy	3,327		Conglomerate
					2	Arbuckle	3,330		Dolomite
Kruckenberg, 14-19-15W	Jan. 1939; Apr. 1939	160	1,770	7,600	1	Lans. K. C.	3,342		Lime
					1	Arbuckle	3,580		Dolomite
Lanterman, 15-19-11W	Jan. 1935	200	43,553	209,200	4	Lans. K. C.	3,109	6	Lime
					2	Arbuckle	3,235	3	Dolomite
Pospishel, 20-17-15W	June 1939	80	7.355	12,000	2	Arbuckle	3,548	9	Dolomite
Prusa, 20-16-11W	Dec. 1938	800	300,137	416,500	1	Topeka			
					2	Lans. K. C.	3,160	7	Lime
					28	Arbuckle	3,335	17	Dolomite
					2	Reagan	3,310	1	Granite Wash
Prusa North, 18-16-11W	Sept. 1939; May 1939	80		45,800	1	Shawnee; Lans. K. C.; Arbuckle	3,160	7	Lime; Dolomite
					1				
					2				
Prusa Southeast, 34-16-11W	April 1940	80	3,000	3,000	2	Arbuckle	3,394	5	Dolomite
Prusa West, 18-16-11W	June 1939	40		14,620	1	Lans. K. C.; Arbuckle	3,207	10	Lime
					4				
Rick, 1-19-11W	Aug. 1936	160	32,135	201,400	5	Arbuckle	3,355	2	Dolomite
Silica, 12-20-11W	Oct. 1931	24,000	6,548,547	29,685,000	9	Lans. K. C.	2,955	95	Limestone
					713	Arbuckle	3,328	19	Dolomite
Trapp (see Russell County)									
Wondra, 15-17-12W	Jan. 1940	40	350	350	1	Lans. K. C.	3,054	20	Limestone
Butler County			4,591,140		2,670				
Augusta North, 28-27-4E	Jan. 1914	1,280	107,400	13,313,752	67	Kans. City	1,900	35	Limestone
						Layton	2,000		
						Wilcox	2,380	10	Sandstone
						Arbuckle	2,410	5	Dolomite
Augusta South, 21-28-4E	Jan. 1916	9,000	235,900	33,495,600	145	Kans. City			Limestone
						Ft. Scott			Limestone
						Wilcox	2,445	10	Sandstone
						Arbuckle	2,600	5	Dolomite
Bausinger, 24-27-3E	July 1929	200	8,640		5	Wilcox	3,050	29	Sandstone

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl. In 1940	Production, Bbl. Cumulative	Number Wells Producing	Producing Horizon Name	To Top, Ft.	Thickness, Ft.	Character
Benton, 10-26-3E	Jan. 1925	80	5,400		2	Chat	2,765	5	I.R.
Blankenship, 2-26-8E	Jan. 1921	1,200	70,200		88	Bartlesville	2,650	50	Sandstone
Brandt, 15-28-7E	June 1936	800	220,133	419,330	37	Chat	2,692	8	I.R.
DeMoss, 5-28-7E	Oct. 1924	400	108,000		17	Bartlesville Burgess	2,700 2,732	 10	Sandstone
Douglass, 2-29-4E	Jan. 1916	2,400	86,400		29	Lans. K. C. Varner	1,790 2,835	40 50	Lime
Elbing, 8-23-4E	Aug. 1918	1,800	414,000		74	Lans. K. C. Viola	2,330 2,430	70 40	Lime
El Dorado, 29-25-5E	Jan. 1917	25,000	2,252,000	176,870,279	1,626	Admire Lans. K. C. Viola Simpson Arbuckle	600 1,700 2,500 2,510 2,550	10 20 5 15 5	Sandstone Lime Lime Sandstone Dolomite
Ferrell, 28-28-8E	March 1939	80	20,888	36,799	3	Mis. lime	2,647	42	Lime
Fox Bush, 25-28-5E	Jan. 1917	5,000	126,000		164	Bartlesville	2,730	40	Sandstone
Garden, 32-26-6E	March 1928	1,600	52,560		30	Bartlesville	2,760	10	Sandstone
Gelwich, 6-27-4E	April 1930	80	14,400		2	Viola	2,924	2	Lime
Haverhill, (15-34)-27-5E	April 1927	700	126,000	3,159,243	61	Bartlesville	2,700	50	Sandstone
Keighley, (14-33)-27-7E	Jan. 1925	1,800	51,120		52	Bartlesville	2,650	50	Sandstone
Kramer, 4-28-6E	Jan. 1926	500	36,000		17	Viola Wilcox Arbuckle	3,050 3,020 3,040	3 15 5	Lime Sandstone Dolomite
Leon, 19-27-6E	Oct. 1926	500	27,720		21	Chat Viola	2,660 3,050	50	I.R. Lime
McCullouch, 1-28-6E	Feb. 1926	400	52,494	357,289	8	Wilcox	3,169	6	Sandstone
McCaig, 13-28-6E	March 1937	80	3,350	21,750	2	Bartlesville	2,720	28	Sandstone
Moore, 12-25-3E		120	4,320		3	Mis. lime	2,667	9	Lime
Potwin, 36-24-3E	Jan. 1921	3,200	223,200		77	Kans. City Mis. lime	2,550 2,660	5 95	Lime Lime
Shaffer, 4-27-6E	June 1926	900	90,000		25	Mis. lime Viola	2,760 3,125	10 25	Lime Lime
Seward, 14-27-7E		600	14,400	946,600	14	Bartlesville	2,650	50	Sandstone
Smock-Sluss, 19-26-6E	March 1918	1,500	54,000		42	Bartlesville Viola	2,685 3,000	30	Sandstone
Snowden-McSweeney, 2-29-6E	1930	160	4,015		1	Mis. lime	2,833		Lime
Steinhoff, 21-29-6E	Jan. 1926	160	3,400		3	Chat	2,803	5	I.R.
Stern, 27-27-6E	Jan. 1928	600	85,000		17	Chat Viola	2,752 3,150	8	I.R.
Weaver, 1-28-5E	Jan. 1929	400	1,200		5	Bartlesville	2,690		Sandstone
Young, 27-26-7E	1919	900	73,000		33	Kans. City Chat	2,190 2,650	5 50	Lime I.R.
Clark County									
Morrison, 17-32-21W	Oct. 1936	160	17,000	112,650	2	Viola	6,467	4	Lime
Coffey County									
Van Noy (1-14)-23-14E (6-18)-23-15E		700	21,600		37	Peru Chat	1,138 1,622	12 6	Sandstone I.R.
Cowley County			2,507,991		662				
Baird, 16-34-3E		160	8,981		4	Bartlesville	3,260		Sandstone
Biddle, 12-32-4E		600	37,000		22	Stalnaker Kans. City	2,300 2,600		Sandstone Lime
Brown, 13-31-7E	Sept. 1922	40	1,825	200,000	1				
Burden, 22-31-6E	Jan. 1926	1,200	54,000		33	Bartlesville	2,865	35	Sandstone
Carson, 19-32-3E	Oct. 1924	400	60,100	3,049,658	18	Layton Arbuckle	2,600 3,450		Sandstone Dolomite
Clarke, 6-31-4E	Jan. 1914	180	12,600		4	Bartlesville	2,840		Sandstone
Couch, 13-30-5E	May 1937	400		53,000	10				
Countryman, 4-33-7E		600	9,125		5	Layton	1,950		Sandstone
Darien, 33-30-4E	June 1939	200	39,000	63,636	6	Arbuckle	3,286	1	Dolomite
David, 35-30-4E	July 1935	800	75,900	442,776	21	Bartlesville	2,935	40	Sandstone
David South, 11-31-4E 2-31-4	Jan. 1934	200	11,000	79,500	5 1	Bartlesville Arbuckle	3,010 3,463	19 3	Sandstone Dolomite
Dexter, 24-33-6E	Jan. 1903	1,200	3,700		1	Mis. lime	2,750		Lime
Dunbar, 29-30-5E	Sept. 1938	40	900	6,109	1	Kans. City	2,229	36	Lime
Eastman, 31-30-6E	Jan. 1924	1,200	43,200	2,332,324	33	Bartlesville	2,770	100	Sandstone
Falls City, 17-35-7E	Jan. 1916	600	10,800	1,163,976	13	Stalnaker	2,000		Sandstone
Ferguson West, 21-30-8E		200	35,000		10				

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl. In 1940	Production, Bbl. Cumulative	Number Wells Producing	Producing Horizon Name	To Top, Ft.	Thickness, Ft.	Character
Frog Hollow, 20-32-5E	Jan. 1937	600	180,000	465,056	24	Bartlesville	3,089	8	Sandstone
Geuda Springs, 8-34-3E	May 1936	600	33,000	252,544	10 1	Bartlesville Chat	3,320		Sandstone I.R.
Graham, 9-33-3E	June 1924	800	23,200	2,466,537	13	Layton Arbuckle	2,550 3,500		Dolomite
Grand Summit, 10-31-8E		600	28,500		14				
Hittle, 21-31-4E	Jan. 1926	2,400	698,900	2,366,300	72	Stalnaker Arbuckle	2,400 3,280	8	Dolomite
Mahannah, 6-30-8E	1918	80	2,500		2	Burgess	2,730		Conglomerate
Murphy, 8-35-3E	Jan. 1933	600	32,000		12	Chat	3,300		I.R.
Olsen, 1-35-7E	Apr. 1921	300	3,800		6	Ft. Scott	2,400		Lime
Rahn, 13-34-5E	Oct. 1939	40	7,900	8,130	1	Bartlesville	2,915	30	Sandstone
Rainbow Bend, 20-33-3E	Dec. 1923	2,000	447,600	73,000,646	115	Burgess	3,200	50	Sandstone
Reidy, 31-31-8E		160	1,100		3				
Rock, 15-30-4E	Jan. 1923	500	37,000	1,458,993	25	Bartlesville	2,760	45	Sandstone
Rock West, 16-30-4E	Oct. 1937	160	114,600	260,479	10	Bartlesville	2,784	18	Sandstone
Rock North, 3-30-4E	Sept. 1937	200	19,960	50,673	5	Bartlesville	2,807	21	Sandstone
Smith, 10-31-3E	Jan. 1917	600	13,000		12	Bartlesville	3,050		Sandstone
State, 15-32-4E	Jan. 1926	1,500	70,000		32	Layton Arbuckle	2,300 3,500		Sandstone Dolomite
Trees, 19-30-4E	Jan. 1934	300	42,000		10	Bartlesville	2,975	25	Sandstone
Turner, 30-32-6E	June 1937	240	21,600	138,998	6	Layton	2,232	15	Sandstone
Udall, 28-30-3E		40	2,100	47,560	1				
Wethered, 28-31-3E	July 1935	1,000	193,100	1,891,820	2 2 27	Lans. K. C. Mis. lime Arbuckle	2,455 3,065 3,400	85	Lime Lime Dolomite
Wilson, 9-33-6E	Nov. 1938	200	25,000	56,878	5	Arbuckle	3,519	4	Dolomite
Winfield, 36-32-4E	Nov. 1914	5,000	108,000		63	Admire Peacock Layton Bartlesville Arbuckle	600 1,400 2,300		Sandstone Sandstone Sandstone Sandstone Dolomite
Elk County			460,720		273				
Bush-Denton, 3-30-9E		2,000	36,000		43				
Collyer, 25-30-10E		400	10,800		8				
Dory, 19-30-9E		120	1,400		3				
Dunkelberger, 27-29-10E		800	70,000		19				
Ferguson East, 23-30-8E		80	4,000		2				
Key, 26-31-10E		320	1,000		8				
Mills, 23-30-10E		160	4,000		4				
Moline, 3-31-10E	Dec. 1927	5,000	20,000		28	Encill. Mis. lime	1,150 1,980		Sandstone Lime
Oliver, 35-31-10E		120	720		3				
Porter, 12-29-8E		800	13,000		19				
Rettig, 19-31-10E		100	None		2				
Sellars, 11-31-9E	July 1937	100		13,471	2	Mis. lime	2,300	22	Lime
Severy, 16-28-11E		2,000	108,000		42				
Webb, 28-31-10E	Oct. 1924		190,000		95	Encill. Red Ft. Scott Arbuckle	1,100 1,350 1,650 2,286		Sandstone Sandstone Lime Dolomite
Walker, 5-31-10E		160	1,800		4				
Ellis County			6,484,185	16,804,342	633				
Bemis-Shutts, 16-11-17W	Oct. 1935	10,240	3,865,037	11,706,700	368	Arbuckle	3,380	2	Dolomite
Bemis-Shutts West, 20-11-17W	Sept. 1940	120	37,273	34,273	3	Arbuckle			
Bemis South, 2-12-17W	Dec. 1938	40	8,325	17,100	1	Arbuckle	3,592	11	Dolomite
Blue Hill, 14-12-16W	Aug. 1937	640	97,931	179,500	3 11 2 1	Topeka Lans. K. C. Arbuckle Wilcox	3,030 3,072 3,360 3,391	33 25 1	Lime Lime Dolomite
Burnett, 1-11-18W	Sept. 1937	3,600	1,772,869	2,098,500	2 136	Lans. K. C. Arbuckle	3,350 3,570	8 4	Limestone Dolomite
Catherine, 3-13-17W	June 1936	160	18,723	112,600	4	Lans. K. C.	3,262	88	Lime
Emmeram, 4-13-16W	June 1937	40	7,521	36,112	1	Lans. K. C.	3,260	7	Lime
Haller, 10-11-18W	July 1936	40	1,373	13,260	1	Topeka	3,036	9	Lime
Herzog, 30-13-16W	June 1940	80	6,740	6,740	2	Arbuckle	3,450	8	Dolomite
Koblitz, 23-12-18W	Feb. 1937	600	41,699	44,307	6	Arbuckle	3,694	4	Dolomite
Kraus, 22-14-9W	July 1936	100	6,589	52,400	2	Sooy	3,735	5	Conglomerate
Marshall, 36-11-18W	Nov. 1936	1,000	107,921	467,500	18	Arbuckle	3,638	12	Dolomite

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl.		Number Wells Producing	Producing Horizon			
			In 1940	Cumulative		Name	To Top, Ft.	Thickness, Ft.	Character
Penny Wahn, 13-15-20W	Sept. 1936	40	6,817	25,900	1	Sooy	3,653	3	Conglomerate
Richards, 5-11-18W	Jan. 1938	120	14,525	66,900	2	Lans. K. C.	3,332	41	Lime
Ruder, 17-15-18W	Aug. 1935	700	66,127	632,600	12 2	Lans. K. C. Arbuckle	3,422 3,572	18 10	Lime Dolomite
Solomon, 28-11-19W	June 1936	160	17,999	48,400	3	Arbuckle	3,629	3	Dolomite
Toulon, 3-14-17W	Dec. 1935	200	32,474	147,850	3 1	Lans. K. C. Arbuckle	3,298 3,512	5 48	Lime Dolomite
Ubert, 12-13-18W	Nov. 1936	160	25,397	123,500	5	Arbuckle	3,707		Dolomite
Walter, 2-12-18W	May 1936	1,400	348,371	987,200	1 40	Topeka Arbuckle	3,160 3,619	5	Lime Dolomite
Ellsworth County			3,722,661	14,871,600	294				
Breford, 7-17-10W	Sept. 1932	700	222,238	1,140,550	10 9	Lans. K. C. Arbuckle	3,140 3,368	12 27	Lime Dolomite
Heiken, 25-17-10W	Oct. 1930	320	14,054	338,500	4	Arbuckle	3,269	2	Dolomite
Lorraine, 13-17-9W	Nov. 1934	5,500	536,946	7,827,150	25 60	Lans. K. C. Arbuckle	3,060 3,200	140 5	Lime Dolomite
Stoltenberg, 21-16-10W	June 1931	4,800	2,584,953	4,833,122	133	Arbuckle	3,333	14	Dolomite
Stoltenberg Southwest, 20-16-10W	July 1940	80	3,870	3,870	2	Arbuckle			
Stoltenberg West, 17-16-10W	March 1940	160	7,600	7,600	4	Arbuckle	3,365	8	Dolomite
Wilkins (now includes Schroeder), 13-17-10W	Apr. 1934	1,800	353,000	720,807	45	Arbuckle	3,260	20	Dolomite
Finney County									
Nunn, 27-21-34W	June 1938	800	34,000	87,105	2	Mis. lime	4,654	10	Lime
Graham County									
Morel, 15-9-21W	Apr. 1938	1,200	94,148	112,500	6	Arbuckle	3,718	2	Dolomite
Penokee, 11-8-24W	Nov. 1940	40	150	150	1	Lans. K. C.	3,750	6	Limestone
Greenwood County			2,958,156		2,605				
Atyeo-Pixlee, 6-22-10E	Jan. 1923	1,000	114,000		96	Bartlesville	2,327	50	Sandstone
Blackwell, 16-24-13E	Jan. 1923	1,000	3,600		5	Mis. lime	2,327		Lime
Browning, 8-22-10E	Jan. 1924	3,800	148,000		95	Bartlesville	2,314	76	Sandstone
Burkett, 13-23-10E	Jan. 1924	2,700	87,000		103	Bartlesville	2,000	100	Sandstone
Christy, 36-24-12E		2,000	4,380		10	Bartlesville	1,500	75	Sandstone
DeMalorie-Souder, 19-21-10E	Jan. 1924	4,500	252,000		126	Bartlesville	2,150		Sandstone
Dunaway, 4-22-13E		1,000	70,000		60	Mis. lime	1,800		Lime
Eureka, 35-25-10E	Jan. 1920	1,200	12,500		12	Mis. lime	2,000		Lime
Fankhouser, 30-21-12E	Jan. 1926	2,500	46,000		65	Bartlesville	1,750		Sandstone
Gaffney, 6-24-11E	Aug. 1926	500	10,756	234,500	3				
Hamilton, 26-23-11E	Jan. 1929	3,000	86,000		96	Bartlesville	1,765	72	Sandstone
Hinchman, 17-24-13E		200	11,000		13	Mis. lime	1,600	50	Lime
Lamont, 5-22-12E	Jan. 1927	2,600	123,000		108	Bartlesville	1,650		Sandstone
Madison, 1-22-11E	Jan. 1921	3,000	176,000		102	Bartlesville	1,800		Sandstone
Polhamus, 27-24-9E	Jan. 1922	1,400	27,000		45	Bartlesville	2,170		Sandstone
Quincy, 18-25-14E	Jan. 1926	3,600	190,000		115	Bartlesville	1,420		Sandstone
Reece, 21-26-9E		1,200	47,500		22	Mis. lime	2,100		Lime
Sallyards, 17-25-9E	Jan. 1921	8,000	144,000		132	Bartlesville	2,350	150	Sandstone
Scott, 19-23-9E	Jan. 1925	2,500	107,000		73	Bartlesville	2,525	75	Sandstone
Seeley-Wick, 22-22-11E	Jan. 1922	7,000	236,000		328	Bartlesville	1,930	45	Sandstone
Smith-Jobe, 10-24-13E	Sept. 1938	40	720		1	Mis. lime	1,662	3	Lime
Teeter, 36-22-9E	Jan. 1922	4,000	240,000		204	Bartlesville	2,400	150	Sandstone
Teichgraber, 2-25-8E		900	22,300		22	Bartlesville	2,450		Sandstone
Thrall, 28-23-10E	1921	7,000	216,000		255	Bartlesville	2,190	166	Sandstone
Virgil, 13-24-12E	Jan. 1916	4,800	107,000		118	Bartlesville Burgess Mis. lime	1,550 1,700 1,700	 10 	Sandstone Conglomerate Lime
Virgil North, 3-23-13E		8,000	410,000		292	Bartlesville Mis. lime	1,550 1,700		Sandstone Lime
Wiggins, 7-24-11E	Jan. 1925	2,500	45,000		46	Bartlesville	1,860	15	Sandstone
Wilkerson, 6-25-9E		1,300	13,200		14	Bartlesville	2,300		Sandstone
Willard, 7-27-11E		1,000	8,200		3				
Harvey County			681,311	19,729,731	135				
Halstead, 36-22-2W	April 1929	1,200	132,514	1,176,700	21	Chat	3,005	30	I.R.
Hollow-Nikkel, 30-22-3W	Dec. 1931	1,500	505,500	18,261,707	107	Lans. K. C. Chat Hunton Simpson Arbuckle	2,499 3,195 3,507 3,500	21 13 2 14	Lime I.R. Lime Sandstone
Sperling, 23-22-2W	Jan. 1935	500	43,300	291,324	7	Hunton Simpson	3,279 3,447	66 16	Lime Sandstone

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl. In 1940	Production, Bbl. Cumulative	Number Wells Producing	Producing Horizon Name	To Top, Ft.	Thickness, Ft.	Character
Kingman County									
Cunningham, 30-27-10W	Jan. 1931	1,400	288,470	2,206,003	49	Lans. K. C.	3,390	74	Lime
						Viola	3,925	33	Lime
Marion County			546,500		160				
Covert-Sellers, 1-21-4E	Sept. 1920	2,400	23,000		18	Viola	2,330	5	Lime
Florence, 20-21-5E	Dec. 1929	3,000	44,500		18	Viola	2,300	10	Lime
Hillsboro, 12-19-2E	Oct. 1927	300	54,000	1,761,084	10	Viola	2,800		Lime
Lost Springs, 22-17-4E	Sept. 1926	2,400	397,000		75	Chat	2,365		I.R.
Peabody, 5-22-4E	Sept. 1929	3,000	28,000		39	Viola	2,532		Lime
McPherson County			4,008,544	67,350,664	751				
Bitikofer, 1-20-1W	May 1940	40	1,160	1,160	1	Chat	2,885	24	I.R.
Bornholdt, 30-20-5W	Aug. 1937	2,400	832,464	907,400	143	Chat	3,292	43	I.R.
Canton North, 28-18-1W	July 1936	40	7,500	58,268	1	Chat	2,803	29	I.R.
Chindberg, 18-19-2W	Jan. 1929	700	97,000	1,223,460	6	Lans. K. C.	2,363		Lime
					25	Chat	3,007		I.R.
Graber, 32-21-1W	May 1934	2,800	843,400	5,035,378	3	Chat			I.R.
					2	Misener	3,323	3	Sandstone
					125	Hunton	3,274	24	Lime
					1	Simpson	3,398	8	Sandstone
Henne, 21-17-1W	Nov. 1940	40	820	820	1	Chat	2,658	4	I.R.
Johnson, 35-19-3W	Feb. 1932	1,200	91,600	2,538,165	16	Chat	3,032	14	I.R.
Lindsborg, 8-17-3W	Jan. 1938	160	29,600	47,332	2	Viola	3,352	21	Lime
McPherson, 29-18-2W	Sept. 1926	2,000	65,100	867,585	28	Lans. K. C.	2,340	55	Lime
						Chat	2,967	11	I.R.
						Viola	3,140	6	Lime
Ritz-Canton, 1-20-2W	July 1929	13,000	1,363,500	33,550,373	271	Lans. K. C.	2,360	39	Lime
						Chat	2,935	31	I.R.
						Viola	3,412	2	Lime
						Simpson	3,440	4	Sandstone
Roxbury, 18-17-1W	Nov. 1938	250	119,600	178,855	28	Chat	2,684	5	I.R.
Voshell, 9-21-3W	Aug. 1929	3,500	556,800	22,941,868	93	Chat	3,095	15	I.R.
						Viola	3,301	3	Lime
						Simpson	3,322	3	Sandstone
						Arbuckle	3,394	10	Dolomite
Ness County									
Aldrich, 7-18-25W	Oct. 1929	2,000	122,200	240,356	13	Ft. Scott	4,378	21	Lime
						Mis. lime	4,428	2	Lime
Norton County									
Van Patten, 26-4-21W	May 1939	40	None	None	1	Lans. K. C.	3,475	21	Lime
Pawnee County									
Pawnee Rock, 13-20-16W	Sept. 1936	640	41,400	133,162	9	Arbuckle	3,825	16	Dolomite
Phillips County									
Bow Creek, 25-5-18W	May 1939	40	7,400	10,925	1	Lans. K. C.	3,111	53	Lime
Ray, 32-5-20W	Aug. 1940	300	8,000	8,000	6	Lamotte	3,540	13	Sandstone
Pratt County			44,050	87,736	7				
Cairo, 7-28-11W	Dec. 1939	160	9,250	9,468	5	Viola	4,267	16	Lime
Luka, 11-27-13W	Aug. 1937	200	34,800	78,268	2	Simpson	4,292	7	Dolomite
					1	Arbuckle	4,354	13	Dolomite
Reno County			3,233,300	35,162,593	496				
Abbyville, 24-24-8W	Jan. 1927	1,200	25,900	372,878	4	Lans. K. C.	3,540	9	Lime
Buhler, 25-22-5W	April 1938	500	74,800	297,159	1	Viola	3,890	19	Lime
					10	Simpson	3,897	5	Sandstone
Burrton, 23-23-4W	Feb. 1931	5,000	2,607,100	30,569,407	337	Chat	3,266	42	I.R.
					72	Hunton	3,583	6	Lime
					1	Arbuckle	3,775	9	Dolomite
Hilger, 16-26-4W	March 1934	600	254,000	1,763,459	32	Viola	4,062	5	Lime
Lerado, 11-26-9W	Dec. 1935	1,800	265,000	2,090,670	1	Lans. K. C.	3,535	4	Lime
					32	Viola	4,128	28	Lime
Yoder, 34-24-5W	Oct. 1935	500	6,500	69,020	6	Chat	3,450	51	I.R.
Rice County			6,214,330	51,143,745	853				
Brandenstein, 10-19-10W	Nov. 1933	160	16,100	359,951	2	Lans. K. C.	3,014	12	Lime
Bredfeldt, 7-18-9W	April 1937	40	1,300	13,746	1	Arbuckle	3,223	17	Dolomite
Bredfeldt West, 12-18-10W	Dec. 1939	40	13,950	14,000	1	Arbuckle	3,260	8	Dolomite
Campbell, 28-19-9W	Jan. 1938	800	254,700	693,350	3	Lans. K. C.	3,195	13	Lime
					25	Arbuckle			Dolomite
Chase, 32-19-9W	March 1931	4,800	1,691,700	20,381,691	3	Lans K. C.	2,942	12	Lime
					234	Arbuckle	3,246	38	Dolomite
Doran, 13-19-10W	Sept. 1936	160	15,200	105,914	3	Arbuckle	3,291	20	Dolomite
Edwards, 3-18-8W	Jan. 1936	2,000	511,500	2,122,498	68	Arbuckle	3,278	5	Dolomite

TABLE I.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl.		Number Wells Producing	Producing Horizon			
			In 1940	Cumulative		Name	To Top, Ft.	Thickness, Ft.	Character
Genesea, 25-18-8W.....	May 1934	4,600	1,324,500	5,090,100	154	Arbuckle	3,231	40	Dolomite
Guldner, 16-18-9W.....	July 1935	160	13,150	236,789	3	Lans. K. C.	2,884	41	Lime
						Arbuckle	3,227	3	Dolomite
Haferman, 6-19-9W....	June 1936	700	78,900	418,838	9	Arbuckle	3,192	24	Dolomite
Heinz, 8-18-10W.......	July 1938	80	9,360	26,502	1	Lans. K. C.	3,000	19	Lime
						Arbuckle	3,254	14	Dolomite
Karber, 7-19-10W......	Oct. 1940	160	6,230	6,230	3	Arbuckle	3,343	7	Dolomite
Keesling, 10-20-9W....	April 1935	700	275,300	2,612,761	47	Arbuckle	3,239	26	Dolomite
Lyons, 14-20-8W......	Nov. 1939	40	6,100	6,987	1	Simpson	3,280	4	Dolomite
Midway, 8-20-9W......	April 1939	240	49,400	85,089	6	Arbuckle	3,244	19	Dolomite
Orth, 27-18-10W.......	July 1932	1,000	57,100	637,862	1	Lans. K. C.	2,915	21	Lime
					10	Pre-Cam.	3,240	3	Quartzite
Orth East, 25-18-10W..	Nov. 1939	120	28,150	28,150	3	Pre-Cam.	3,230	12	Quartzite
Ploog, 33-18-9W.......	June 1930	300	69,500	1,166,770	10	Arbuckle	3,252	19	Dolomite
Ponce, 28-21-7W.......	April 1936	40	4,900	25,397	1	Sooy	3,388	40	Conglomerate
Raymond, 21-20-10W..	June 1929	1,000	269,500	5,791,853	5	Lans. K. C.	3,130	10	Lime
					33	Arbuckle	3,330	21	Dolomite
Rickard, 22-18-9W.....	Oct .1935	40	6,900	51,160	1	Arbuckle	3,324	41	Dolomite
Welch, 2-21-6W........	April 1924	1,500	113,630	4,200,650	28	Chat	3,370	44	I.R.
Welch North, 23-20-6W	June 1937	160	7,500	37,631	3	Chat	3,334	32	I.R.
Wenke, 7-20-10 W.....	Mar. 1935	300	46,600	256,022	7	Arbuckle	3,360	13	Dolomite
Wenke West, 18-20-10W	Oct. 1938	80	19,360	29,916	2	Arbuckle	3,292	5	Dolomite
Wherry, 11-21-7W.....	Sept. 1933	7,200	1,305,000	6,672,561	193	Sooy	3,358	22	Conglomerate
Wherry East, 12-21-7W	Sept. 1937	160	18,800	70,927	3	Sooy	3,455	14	Conglomerate
Rooks County..............			351,098	1,214,075	65				
Dopita, 31-8-17W......	April 1934	160	28,800	105,820	2	Lans. K. C.	3,212	5	Lime
					5	Arbuckle	3,409	10	Dolomite
Faubin, 12-6-18W......	Feb 1936	80	4,800	37,900	2	Lans. K. C.	3,128	22	Lime
Kruse, 3-10-16W.......	Jan. 1928	40	198	10,400	1	Lans. K. C.	3,115	6	Lime
Laton, 11-9-16W.......	July 1927	400	219,100	572,146	39	Lans. K. C.	3,228	33	Lime
Stockton, 26-7-17W....	April 1937	160		23,000	2	Lans. K. C.	3,118	62	Lime
Webster, 21-8-19W....		40	2,250	39,747	1	Arbuckle	3,434	1	Dolomite
Westhusin, 11-9-17W...	Nov. 1936	400	73,600	311,813	11	Lans. K. C.	3,231	11	Lime
Zurich, 26-10-19W.....	Sept. 1934	200	15,500	106,249	2	Lans. K. C.	3,340	9	Lime
Rush County...............									
Otis, 10-18-16W.......	July 1934	600	288,370	1,396,897	17	Lamotte	3,527	9	Sandstone
Winget, 15-16-16W....	Dec. 1936	80	3,300	45,629	3	Lans. K. C.	3,243	4	Lime
					1	Arbuckle	3,537	8	Dolomite
Russell County............			12,004,325	68,200,946	1,535				
Atherton, 30-13-14W...	July 1935	1,800	270,700	874,914	9	Lans. K. C.	3,008	47	Lime
					27	Arbuckle	3,284	5	Dolomite
Atherton North, 18-13-14W................	June 1939	40	1,800	3,919	1	Arbuckle	3,130	3	Dolomite
Big Creek, 36-14-15W..	July 1935	1,000	269,200	1,493,983	1	Lans. K. C.	2,908	42	Lime
					24	Gorham	3,152	5	Sandstone
					2	Arbuckle	3,171	5	Dolomite
Big Creek East, 31-14-14W................	July 1938	200	59,540	79,647	5	Lans. K. C.	3,180	15	Lime
					3	Arbuckle	3,149	4	Dolomite
Boxberger, 36-15-15W..	Dec. 1935	160	10,320	126,520	4	Lans. K. C.	3,147	4	Lime
Bunker Hill, 31-13-12W	Oct. 1935	160	10,700	64,612	4	Lans. K. C.	2,965	16	Lime
Davidson Northeast, 34-15-11W..........	Dec. 1940	40	None	None	1	Gorham	3,309	4	Sandstone
Donovan, 10-15-15W...	Feb. 1935	40	5,700	32,376	1	Lans. K. C.	3,193	7	Lime
Driscoll, 30-15-11W....	June 1940	80	4,000	4,000	1	Sooy	3,323	3	Conglomerate
					1	Arbuckle	3,255	5	Dolomite
Dubuque, 34-15-12W...	Oct. 1935	160	15,300	145,677	3	Arbuckle	3,275	3	Dolomite
Eichman, 34-15-14W...	May 1935	800	37,700	616,015	6	Arbuckle	3,316	10	Dolomite
Fairfield, 22-15-13W...	Dec. 1938	40	2,250	6,081	1	Arbuckle	3,352	5	Dolomite
Fairfield North, 16-15-13W...............	Jan. 1939	400	35,000	89,218	2	Lans. K. C.	3,112	5	Lime
					8	Arbuckle	3,232	4	Dolomite
Fairport, 8-12-15W....	Nov. 1923	3,600	630,400	14,442,874	145	Lans. K. C.	2,950	12	Lime
						Gorham	3,211	5	Sandstone
Foster, 19-15-15W.....	May 1938	40	2,300	12,870	1	Lans. K. C.	3,114	2	Lime
Gideon, 8-15-14W......	June 1930	40		37,750	1	Sooy	3,266	7	Conglomerate
Gorham, 5-14-15W.....	Oct. 1926	7,000	2,185,500	17,034,448	1	Tarkio	2,525	25	Lime
					11	Topeka	2,765	15	Lime
					144	Lans. K. C.	3,027	30	Lime
					2	Arbuckle	3,289	4	Dolomite
					146	Lamotte	3,299	1	Sandstone
Greenvale, 4-15-12W...	April 1938	320	88,940	154,152	8	Lans. K. C.	3,040	5	Lime
					6	Arbuckle	3,267	21	Dolomite

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl. In 1940	Production, Bbl. Cumulative	Number Wells Producing	Producing Horizon Name	To Top, Ft.	Thickness, Ft.	Character
Greenvale Northwest, 32-14-12W	Nov. 1940	40	None	None	1	Lans. K. C.	2,956		
Hall-Gurney, 30-14-13W	Oct. 1931	14,000	2,214,800	5,981,348	2	Wabaunsee			Sandstone
					3	Topeka	2,675		Lime
					269	Lans. K. C.	2,985	15	Lime
					29	Gorham	3,165	4	Sandstone
					4	Arbuckle	3,451	3	Dolomite
					12	Lamotte	3,129	1	Sandstone
					3	Pre-Cam.	3,156	25	Granite
Karst, 27-15-14W	Oct. 1935	160	28,600	173,950	5	Arbuckle	3,315	4	Dolomite
Lewis, 28-14-12W	Sept. 1940	40	1,570	1,570	1	Wabaunsee	2,317	12	Limestone
Mahoney, 8-14-12W	June 1940	120	6,300	6,300	3	Lans. K. C.	2,977	3	Lime
Neidenthal, 23-14-15W	Aug. 1934	600	47,300	842,148	10	Arbuckle	3,246	4	Dolomite
Russell, 22-13-14W	Feb. 1934	1,200	356,850	4,389,246	3	Lans. K. C.	3,195	9	Lime
					46	Arbuckle	3,280	6	Dolomite
Sellens, 26-15-13W	July 1929	1,200	155,000	2,360,973	26	Lans. K. C.	3,088	9	Lime
						Arbuckle	3,352	13	Dolomite
Steinert, 21-15-15W	March 1936	40	3,850	35,742	1	Lans. K. C.	3,060	36	Lime
Trapp, 23-15-14W	Oct. 1939	26,640	5,322,000	18,335,806	2	Topeka	2,889	7	Lime
					34	Lans. K. C.	3,062	2	Lime
					1	Sooy			Conglomerate
					557	Arbuckle	3,252	3	Dolomite
Trapp West, 15-15-14W	July 1939	160	28,265	37,913	4	Arbuckle	3,249	7	Dolomite
Vaughn, 17-14-14W	April 1937	1,000	203,540	771,371	22	Lans. K. C.	3,004	30	Lime
					2	Gorham	3,282	7	Sandstone
					4	Arbuckle			Dolomite
Williamson, 9-14-14W	Feb. 1936	160	6,900	45,523	2	Tarkio	2,522	28	Lime
Scott County									
Shallow Water, 15-20-33W	Dec. 1934	600	152,500	902,462	9	Mis. lime	4,670	16	Lime
Sedgwick County	Aug. 1928	4,700	1,152,631	39,847,311	228				
Andover South, 36-27-2E	Nov. 1937	80	None	15,372	1	Simpson	3,098	3	Sandstone
Bentley, 19-25-1W	April 1934	40		12,600	1	Lans. K. C.	2,911	15	Lime
Cross, 29-25-1W	April 1929	160	4,000	70,000	2	Lans. K. C.	2,690	40	Lime
Eastborough, 19-29-2E	Aug. 1929	1,000	180,000	7,871,661	45	Chat	2,956	14	I.R.
						Viola	3,238	4	Lime
Eastborough North, 8-27-2E	Aug. 1938	80	3,881	4,000	2	Viola	3,258	4	Lime
Goodrich, 16-25-1E	Dec. 1928	640	237,700	2,650,900	34	Lans. K. C.	2,614	2	Lime
						Chat	3,010	10	I.R.
						Misener	3,334	3	Lime
Greenwich, 14-26-2E	May 1929	700	254,000	6,290,162	42	Chat	2,885	3	I.R.
						Viola	3,321	5	Lime
						Simpson	3,350	4	Sandstone
Kuske, 24-25-1E	Jan. 1929	40	2,400	137,440	1	Sooy	3,489	2	Conglomerate
Oatville, 18-28-1E	Nov. 1937	80	1,400	10,170	1	Simpson	3,489	2	Sandstone
Robbins, 20-28-1E	June 1929	420	100,500	2,878,397	52	Mis. lime	3,090	12	Lime
Stitt, 21-27-1W	March 1940	40	1,000	1,000	1	Lans. K. C.		22	Lime
Valley Center	Aug. 1928	1,500	367,700	19,905,609	67	Lans. K. C.	2,579	13	Lime
						Misener	3,368	7	Lime
						Viola	3,366	2	Lime
Stafford County	Oct. 1930	11,100	3,218,360	10,046,498	431				
Bedford, 21-23-12W	Aug. 1940	200	7,829	7,829	5	Arbuckle	3,839	9	Dolomite
Drach, 12-22-13W	Nov. 1937	800	72,000	211,178	9	Arbuckle	3,693	12	Dolomite
Fischer, 31-21-12W	May 1938	120	36,950	74,664	5	Arbuckle	3,641	7	Dolomite
Gates, 27-21-13W	May 1933	640	90,000	579,118	11	Arbuckle	3,679	39	Dolomite
Jordan, 15-25-14W	Nov. 1936	200	33,300	163,727	5	Lans. K. C.	3,722	5	Lime
Kipp, 27-25-14W	Jan. 1937	160	23,600	81,201	4	Lans. K. C.	3,827	79	Lime
Leesburgh, 12-25-13W	April 1938	360	124,900	151,732	9	Arbuckle	4,153	10	Dolomite
Max, 35-21-12W	Aug. 1938	160	33,900	51,433	1	Lans. K. C.	3,356	16	Lime
					5	Arbuckle	3,570	5	Dolomite
Mueller, 29-21-12W	March 1938	80	15,700	87,670	2	Arbuckle	3,594	7	Dolomite
Rattlesnake, 13-24-14W	Oct. 1938	40	8,600	19,698	1	Lans. K. C.	3,608	48	Lime
Richardson, 36-22-12W	Oct. 1930	1,200	497,600	3,863,566	60	Arbuckle	3,537	62	Dolomite
Riley, 28-23-11W	Aug. 1940	40	2,191	2,191	1	Lans. K. C.	3,471	5	Lime
Roach, 12-22-14W	Dec. 1940	40	None	None	1	Arbuckle	3,749	20	Dolomite
St. John, 23-24-13W	April 1935	1,200	176,340	703,468	10	Lans. K. C.	3,588	32	Lime
					10	Arbuckle	4,075	12	Dolomite
Sittner, 33-21-12	Aug. 1937	600	37,000	139,722	2	Lans. K. C.	3,278	36	Lime
					3	Arbuckle	3,600	6	Dolomite
Sittner South, 3-22-12W	May 1938	500	125,700	151,825	18	Arbuckle	3,594	6	Dolomite

southeast of the old Stoltenberg pool proved that this pool is considerably larger than had been thought possible. One of the wildcats mentioned served as a connecting link with the old Stratman pool and the name "Stratman," therefore, has been taken from the record of pools. At the close of 1940 two outpost wells were still far enough removed from the main pool to demand separate pool classification. The names used for these pools are "Stoltenberg Southwest" and "Stoltenberg West." The excitement provoked by these extensions to the old Stoltenberg area spread southeast toward the old Wilkins area, where the number of producing wells is now twice as large as it was a year ago.

Graham County surged prominently into the limelight, although it was only last year that it entered the ranks of the oil-producing counties. Considerable publicity was given to the discovery of a second oil pool (Penokee) in this county, because it was believed that an entirely new producing horizon for Kansas had been found. The discovery well was drilled by Shields on the Paxson farm and was reported to have found oil in the Marmaton group. More recent determinations on well cuttings from the discovery well indicate that it produces from the lower portion of the Lansing-Kansas City limestone series.

In McPherson County the feverish drilling campaign in the Bornholdt area, which began in 1939, continued with unabated fervor during 1940. Connecting wells were drilled between the Bornholdt pool and the Bornholdt North pool, thus eliminating one name from the record. The total number of wells at the close of 1940 was more than 140, compared with only 16 at the beginning of the year. In the northeastern part of the county an attempt to extend the Roxbury pool led to the discovery of a new

TABLE 1.—(*Continued*)

Field and Location	Discovery Date	Area, Acres	Production, Bbl.		Number Wells Producing	Producing Horizon			
			In 1940	Cumulative		Name	To Top, Ft.	Thickness, Ft.	Character
Snider, 3-21-11W	April 1936	320	29,000	170,770	4	Lans. K. C.	3,111	38	Lime
					1	Simpson	3,362	6	Sandstone
					3	Arbuckle	3,324	18	Dolomite
Snider South, 16-21-11W	Aug. 1938	360	38,300	50,729	8	Arbuckle	3,402	7	Dolomite
Stafford, 15-24-12W	Aug. 1940	160	18,900	18,900	4	Viola	3,836	14	Lime
Zenith, 23-24-11W	Sept. 1937	4,000	1,846,550	3,517,086	249	Misener	3,804	20	Sandstone
						Viola	3,860	5	Lime
Sumner County	July 1915	5,700	1,042,110	41,425,217	250				
Anness, 2-30-4E	Oct. 1937	40	7,400	36,698	1	Simpson	4,394	7	Sandstone
Caldwell, 17-35-3W	May 1929	160	54,750	1,330,950	4	Simpson	4,765	19	Sandstone
Churchill, 25-31-2E	July 1926	1,000	174,600	18,321,557	63	Stalnaker	1,820	25	Sandstone
Latta, 9-30-2W	June 1927	200	20,000	62,232	11	Lans. K. C.	3,042	14	Lime
Oxford, 23-32-2E	Aug. 1927	800	153,000	14,283,175	13	Stalnaker	2,020	16	Sandstone
					6	Layton		14	Sandstone
					21	Arbuckle	2,890	3	Dolomite
Oxford West, 17-32-2E	May 1926	160	12,600	488,474	3	Arbuckle			Dolomite
Padgett, 23-34-2E	Oct. 1924	1,800	73,000	1,843,638	20	Chat	3,474	28	I.R.
Rainbow Bend West, 24-33-2E		160	3,860	300,000	3	Burbank			Sandstone
						Arbuckle			Dolomite
Rutter, 21-33-2E	July 1926	40	7,200	46,441	1	Chat	3,315	27	I.R.
Vernon North, 15-35-2E	July 1915	200	34,700	217,146	5	Chat	3,443	22	I.R.
Wellington, 33-31-1W	Dec. 1929	1,200	493,900	4,483,102	98	Chat	3,655	11	I.R.
Zyba, 7-30-1E	Nov. 1937	40	7,100	11,804	1	Simpson	3,866	3	Sandstone
Trego County	Oct. 1934	680	47,765	402,723	13				
Gugler, 36-12-21W	Dec. 1936	40	4,140	18,328	1	Arbuckle	3,830	8	Dolomite
Wakeeney, 14-11-23W	Oct. 1934	640	43,625	384,395	7	Lans. K. C.	3,619	8	Lime
Woodson County									
Big Sandy, 14-26-14E			14,400		20				
Hoagland, 2-24-14E			26,000		20				
Wiede, 32-23-15E			10,500		8				
Winterscheid, 15-23-14E		7,700	216,000		226	Mis. lime	1,575	65	Lime

pool, named the "Henne" pool, after the farm on which the first well was drilled. A second new pool is the Bitikofer, in the east-central part of the county. Thus it appears that Range 4 is now the only range in which no oil pools have been found.

Phillips County, in the far northwestern part of Kansas, also attracted attention during 1940. This county was first mentioned in the report for 1939, when the Bow Creek pool was found. In 1940 the Cities Service Oil Co. drilled a deep test well on the Ray farm, in sec. 32, T.5 S., R.20 W., which found commercial quantities of oil at 3540 ft. in the Lamotte, or Basal sand, of Cambrian age. The large potential of the discovery well encouraged a rapid drilling campaign, so that by the close of the year five producers had been drilled in the new Ray pool.

In Rice County, considerable drilling to the north and northeast of the old Chase pool developed much additional acreage productive of oil. The Cramm and the Soeken pools were joined to the Chase pool during 1939 and by the close of 1940 it appeared that the Campbell pool would also become part of the Chase pool and that the Midway and the Keesling pools might also be absorbed. However, in this report these pools are still treated as separate entities. One new pool was discovered in Rice County—the Karber pool, found by Carlock, sec. 7, T.19 S., R.10 W., when he finished the test well on the Karber farm. It was suggested that this pool be joined to the Rick pool, in Barton County, because it is near that pool, but at the close of the year the Nomenclature Committee voted to regard the Karber as a separate pool.

In Rooks County a rapid drilling campaign in the Laton pool caused that pool to expand to three times its former size. In Russell County, as might be expected, many wells were drilled. A number of the numerous pools of this county were considerably enlarged and five new oil pools were found. Thus this county again leads in the number of new pools recorded. The Greenvale pool was tripled in size and wildcat drilling in its vicinity served to uncover

TABLE 2.—*Producing Gas Fields in Kansas*

Field and Location	Discovery Date	Area, Acres	Production, Thousand Cu. Ft.		Number Wells Producing	Producing Horizon			
			In 1940	Cumulative		Name	To Top, Ft.	Thickness, Ft.	Character
Barber County									
Medicine Lodge, 13-33-13W	Jan. 1927	5,000	7,675,958	44,113,080	32	Chat	4,455	10	I.R.
Edwards County									
McCarty, 31-25-17W	May 1929	40	33,966		1	Sooy	4,545	10	Conglomerate
Harvey County									
Hollow-Nikkel, 30-22-3W	Dec. 1931	1,600	189,736			Chat	3,195		I.R.
Sperling, 23-22-2W	Jan. 1935	600	59,960	6,158,838	2	Chat	2,995	50	I.R.
McPherson County			5,122,903						
Pratt County									
Cairo, 7-28-11W	Nov. 1935	12,000	11,934,153	20,459,515	27	Viola	4,278	8	Lime
Reno County									
Burrton, 23-23-4W	Sept. 1930	5,000	4,674,845	41,597,964	52	Chat	3,298	70	I.R.
Yoder, 34-24-5W	Oct. 1936	800	471,285		4	Chat	3,402	50	I.R.
Rice County									
Lyons, 35-19-8W	July 1888	1,500	2,955,567	8,006,851	{ 1 8	Simpson Arbuckle	3,290 3,277	5 7	Dolomite Dolomite
Orth, 27-18-10W	July 1933	540	674,900		3	Lans. K. C.	2,906	30	Lime
Thurber, 22-21-9W	Oct. 1937	160	405,805	1,601,587	3	Misener	3,317	10	Conglomerate
Rush County									
Otis, 11-18-16W	March 1930	15,000	9,709,900	54,135,900	57	Lamotte	3,507	2	Sandstone
Sumner County									
Wellington, 33-31-1W	Dec. 1929	1,200	639,809		47	Chat	3,655	12	I.R.
Southwest Kansas									
Hugoton, 3-35-34W	1922	2,000,000	33,126,800	222,090,800	286	{ Winfield Ft. Riley Florence	2,755 2,800 2,850	10 10 12	Lime Lime Lime

the new oil deposit known as the Greenvale Northwest pool. The other new pools are the Driscoll, the Lewis, the Mahoney, and the Davidson Northeast pool. The last named lies in the southeastern part of the county and may prove to be an extension of the old Davidson pool, in the Northeastern part of Barton County. In the Lewis pool, oil was found in a limestone near the base of the Wabaunsee group. The Nomenclature Committee decided to name this producing horizon the "Wabaunsee lime," thus establishing a new kind of geological name. The Committee also voted to join the Hall and the Gurney pools, inasmuch as connecting wells were drilled during the year, and to call the pool the Hall-Gurney pool. It also voted to attach the old Fink pool to the same area, thus creating a new pool that contains no less than 13,600 acres. The remarkable Trapp pool was greatly expanded during the year, partly by the addition of the old Anschutz pool, which formerly lay to the northeast of the main pool, and partly through the drilling of many inside locations. This pool now has 678 wells, compared with 549 at the close of 1939. It covers 20,000 acres and the limits are not yet in sight.

In Stafford County interest was not allowed to slacken during the year. The sensational Zenith pool was greatly extended and the number of wells increased by inside drilling. Many of the newer wells produce from the Viola limestone instead of the Misener, which formerly was more important. In other parts of the county wildcatting carried on with determination served to uncover four new oil pools and also new producing horizons in old pools.

TABLE 3.—*New Pools Discovered in Kansas during* 1940

County and Name	Location	Discovery Well	Potential, Bbl.	Producing Zone	Depth, Ft.	Date
Barton:						
Bird	33-18-15 W	Aylward No. 1 Bird	27	Lamotte	3508–3510	April 22
Hammer	35-19-12 W	Carlock No. 1 Hammer	440	Arbuckle	3348–3370	Aug. 20
Prusa Southeast	34-16-11 W	Hinkle No. 1 Krautwurst	15	Arbuckle	3394–3402	April 7
Wondra	15-17-12 W	Phillips No. 1 Wondra	100	Lans. K. C.	3120–3125	Jan. 21
Cowley:						
Baird East	15-34- 3 E	McKnabb No. 1 Snyder	230	Bartlesville	3265–3280	June
Ellis:						
Bemis-Shutts West	17-11-17 W	Champlin No. 1 Hadley	3,000	Arbuckle	3290–3292	Sep. 23
Herzog	30-13-16 W	Gulf No. 1 Sander	312	Arbuckle	3450–3458	June 30
Ellsworth:						
Stoltenberg West	17-16-10 W	Duwe Farris No. 1 Adamek		Arbuckle	3365–3373	March 26
Stoltenberg Southwest	20-16-10 W	Emerich No. 1 Heggy	240	Arbuckle	3349– 51	July 7
Graham:						
Penokee	11- 8-24 W	Shields No. 1 Paxson	220	Lans. K. C.	3750–3756	Nov. 4
Jefferson:						
McLouth	4-10-20 W	McLaughlin No. 1 Mcleod	40	Mis. lime	1594–1596	June 15
McPherson:						
Bitikofer	1-20- 1 W	Aladdin No. 1 Bitikofer	50	Chat	2911–2913	May 8
Coons	13-19- 1 W	Carey Drilling No. 1 Coons	Gas	Mis. lime	2897–2910	Nov. 6
Henne	21-17 -1 W	Williams No. 1 Henne	500	Mis. lime	2658–2662	Nov. 5
Phillips:						
Ray	32- 5-20 W	Cities Service No. 1 Ray	2,135	Lamotte	3540–3553	Aug. 15
Rice						
Karber	7-19-10 W	Carlock No. 1 Karber	280	Arbuckle	3343–3350	Oct. 9
Russell:						
Driscoll	30-15-11 W	Hayes No. 1 Driscoll	650	Sooy	3323–3325	June 26
Greenvale Northwest	32-14-12 W	Magnolia No. 1 Borrell	320	Lans. K. C.	2956–2960	Nov. 26
Lewis	28-14-12 W	Jones No. 1 Lewis	1,460	Wab. lime	2317–2329	Sep. 9
Mahoney	8-14-12 W	Jones No. 1 Mahoney	550	Lans. K. C.	2977–2980	June 26
Davidson Northeast	34-15-11 W	Braden McClure No. 1 Phillips	1,250	Gorham	3312–3313	Dec. 7
Stafford:						
Bedford	21-23-12 W	Shell No. 1 Bean	2,700	Arbuckle	3839–3848	Aug. 18
Riley	28-23-11 W	Shell No. 1 Riley	340	Lans. K. C.	3471–3476	Aug. 25
Roach	12-22-14 W	Thayer No. 1 Roach	120	Arbuckle	3787–3790	Dec. 31
Stafford	15-24-12 W	Stanolind No. 1 "A" Charles	3,000	Viola	3836–3850	Aug. 4

The new pools are the Bedford and the Riley, in the northeastern part of the county; the Stafford pool, near the center of the county; and the Roach pool, in the northwestern part of the county. The Stafford pool produces from the Viola limestone, which is somewhat unusual for this county. In the Sittner South pool the Arbuckle dolomite was added as a new producing horizon. In the Snider South pool the Simpson sand was added as a new producing level.

Important Wildcats

In all, 231 wildcats are listed as having been drilled in Kansas during 1940. Of this total, 174 were drilled in western and 57 in eastern Kansas. Most of them were drilled within 2 miles of the nearest pool or well, and probably would not be considered in this category in some other producing states. In western Kansas, 85 test wells were drilled, which at the time of drilling were more than 2 miles from production. Eleven of these were fortunate enough to open new oil pools. The remaining 65 were dry. These dry tests furnish a great deal of geological information, which can be used to make more accurate locations possible. Only the most interesting ones will be described in this report.

Taking them in alphabetical order by counties, the test well drilled by the Bells Wells Oil Co. in Cloud County will be considered first. This well, sec. 35, T.6 S., R.1 W., found the Lansing at 1980 ft., the Mississippian rocks at 2530 ft. and the Arbuckle dolomite at 3375 ft. The total depth of the hole is 3407 ft. In Gove County, on the western frontier of the oil territory, the Cities Service Oil Co. drilled a test in sec. 36, T.13 S., R.30 W., which encountered the Arbuckle dolomite at a depth of 4615 ft. but was drilled down to a total depth of 5169, where it finished in pre-Cambrian granite. The wildest of the wildcats was drilled in Kearny County by the Stanolind Oil Co., on the Judd ranch. It finally reached a depth of 6071 ft. without finding any shows of oil deemed worthy of a test.

In Ness County, the Aladdin Oil Co. drilled a well on the Jedlicka ranch, sec. 33, T.20 S., R.23 W., in which the Mississippian rocks appeared at 4348 ft. and the Arbuckle dolomite at 4810 ft. The test was drilled 62 ft. deeper without favorable indications, and was abandoned as a dry hole. In Pawnee County a borehole on the Gilkison ranch, drilled by the Derby Oil Co. in partnership with several other companies (sec. 21, T.22 S., R.16 W.) found the Lansing limestone at 3641 ft. and the Arbuckle dolomite at 4105 ft. It was abandoned as a dry hole 20 ft. deeper. In Rooks County, the Cities Service Oil Co. drilled a test well 9 miles west of the Faubin pool, in sec. 5, T.6 S., R.19 W., without favorable indications. Incidentally, it should be noted that the Cities Service Oil Co. drilled more wildcats than any other operating unit. It was responsible for the deep test well on the Hansen ranch, sec. 15, T.6 S., R.19 W., in which the last likely level for oil, the Arbuckle dolomite, was found at 3635 ft. The test was abandoned at a total depth of 3700 feet.

In Sedgwick County, a very significant borehole was drilled by the Sunray Oil Co. on the McMinn farm, in sec. 14, T.29 S., R.2 W. This test is located on a very favorable trend, but had to be abandoned as a dry hole at 4055 ft. after having penetrated the Arbuckle dolomite 25 ft. In the far west, in Sheridan County, a dry hole was drilled on the McGinnis ranch by the Cities Service Oil Co., sec. 10, T.9 S., R.27 W. In this test, which was closely watched by other interested parties, the Lansing limestone appeared at 3835 ft., the Mississippian at 4470 and the Arbuckle dolomite at 4600 ft. It was drilled 265 ft. deeper, but finally abandoned at 4865 ft. because no favorable shows had been found at any level. In Stafford County a number of wildcats were drilled, three of which, as reported

in a previous page, are classed as discovery wells of new pools. One of the rank wildcats, which was not so fortunate, is the test drilled by Seaney on the Boyd ranch in sec. 4, T.21 S., R.14 W. This test was abandoned at a depth of 3646 ft. In Trego County, a very interesting test well was projected by Bartlett as the No. 1 Pfannenstiel, sec. 30, T.13 S., R.25 W. As drilling progressed, the Lansing limestone was found at 3690 ft., the Mississippian at 4288 ft. and the Arbuckle dolomite at 4650 ft. Drilling was continued down to 4684 ft., where the test was abandoned as a dry hole.

Acknowledgments

The author wishes to acknowledge the assistance given by a number of geologists residing in Wichita. Mr. Edward Koester supplied a list of wildcats drilled during the year 1940 and Mr. Anthony Folger supplied important data on new producing horizons and on some of the new pools discovered during the year. Data on total number of wells drilled and their breakdown into oil, gas, dry, wildcat, were furnished by Mr. Zenas Stuckey. The production figures were supplied by Messrs. T. A. Morgan and J. H. Page, of the State Corporation Commission.

Oil and Gas Development in Kentucky during 1940

By Coleman D. Hunter* and George M. Straughan†

Oil and gas development as well as extensive leasing in Kentucky during 1940 has shown a marked improvement over the past three years.‡ The most noticeable improvement is the gas development in eastern Kentucky and the deep tests being drilled by major oil interests.

In western Kentucky, 406 wells were drilled, of which 173 were oil producers, 12 were gas wells and 221 were dry or abandoned. The number of dry tests was large, because no important, new oil or gas pool was discovered and many of the dry holes could be considered wildcat tests. However, with either oil or gas possibilities from Pennsylvanian formations on through Mississippian, Silurian, Devonian, and Ordovician, this percentage of dry holes seems rather high. Many of the dry tests possibly should have been tested in deeper horizons before being abandoned: namely, Silurian and Ordovician ages.

In eastern Kentucky, 213 wells were drilled, of which 113 were gas producers, 61 were oil wells, and 39 were dry holes. Of these wells, 117 were drilled in the most important Big Sandy gas field, in Floyd, Pike, Knott and Martin Counties, and of this number 103 were gas producers, 5 were oil wells, and 9 were dry holes. In the Big Sinking oil field of Estill, Lee and Powell Counties, 70 of the remaining 96 wells were drilled, 56 being oil producers.

During 1940, four deep tests were drilled in eastern Kentucky. One test penetrated the Knox dolomite in Knox County and was dry; no St. Peter sand was encountered. Another test in Lee County had some gas in what might be called St. Peter sand, according to the State Department, and also some gas deeper in the Knox dolomite. In Wolfe County, a small oil well was completed in the Ordovician, which was undoubtedly of Trenton age.

At the present time, four deep tests are being drilled, all of which will go to the Knox dolomite. In Elliott County, on the Burke dome, the Inland Gas Co. is drilling at 3650 ft. In Magoffin County, on the Paint Creek uplift, the Cumberland Petroleum Co. is drilling at 3800 ft. In Clark County, in the Ruckerville fault area, W. O. Allen is drilling at 1800 ft. In Laurel County, on the Sinking Creek dome, the Globe Oil and Gas Co. is drilling at 1750 ft. If production is encountered in the Trenton, St. Peter, or Knox dolomite in any of these tests, eastern Kentucky will experience a marked increase in deep development.

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‡ Detailed tables appear in the Transactions volumes on Petroleum Development and Technology for former years.

Oil and Gas Development in North Louisiana in 1940

By H. K. Shearer,* Member A.I.M.E.

North Louisiana (including all townships north of the Louisiana base line) had a year of normal development in 1940, marked by the discovery of two shallow oil fields producing from the Wilcox formation in La Salle Parish and a large increase in drilling in the old Caddo shallow field. This renewal of shallow drilling activity led to a somewhat unexpected increase in the number of wells drilled, although the total footage and average depth continued to decline, as in several preceding years.

Well completions and depth statistics for 1940, with previous years for comparison, are as follows:

	1937	1938	1939	1940
Oil wells	411	350	278	451
Gas wells	175	117	83	76
Injection wells	0	0	0	9
Dry holes	130	141	160	135
Total	716	608	521	671
Footage drilled	2,863,843	2,322,407	1,758,977	1,722,071
Average depth	3,993	3,820	3,376	2,570
Wildcat producers	7	2	1	6
Wildcat dry holes	58	47	48	55

Wildcat producers in 1940 include the discovery oil wells in the Olla and Nebo fields; also three gas wells in the vicinity of the Olla field and a shallow gas well, which opened a new field or extension in the Greenwood area of Caddo Parish. This table illustrates the lack of important deep discoveries since 1937, in which year the Rodessa, Lisbon and Cotton Valley fields were being actively developed. Operators have been forced to return to the old type of shallow drilling, which necessarily means smaller producing wells.

Oil production in 1940 was 24,381,760 bbl., a decrease of 867,880 bbl. from 1939, or 3.44 per cent. The newly discovered fields of La Salle Parish produced over a million barrels, and other increases worthy of note were at Cotton Valley, Caddo, Sligo and Sugar Creek. The greatest decrease was again at Rodessa, although this remains the principal producing field.

Geological Names Revised

Deep drilling during 1940 did not provide a great deal of new geological information. However, by agreement of a majority of the members of the Shreveport Geological Society, the names of some of the Lower Cretaceous formations have been revised in the interest of greater clarity and in order to make the descriptions agree better with the facts discovered in recent years. The geological section is discussed in detail and reasons for changes in nomenclature are stated in a recent publication by Ralph W. Imlay.*

Although not yet in universal use among field men, the new names are employed in this report and accompanying tables, as

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* Geologist, The Hunter Company, Inc., Shreveport, La.

* R. W. Imlay: Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities. Arkansas Geol. Survey *Inf. Circ.* 12 (1940).

See also stratigraphic section by W. B. Weeks, p. 258, this volume.

it is to be hoped that little or no further revision will be necessary. Formation, rather than group, names are preferred whenever sufficiently detailed information is available. Thus the good Texas name "Trinity group," formerly applied to all Lower Cretaceous beds below the Fredericksburg, and later restricted to Paluxy, Glen Rose and original Travis Peak, still takes in beds of such great thickness and diverse character that the name has little practical significance in north Louisiana. The term "Glen Rose" is useful only in areas where basinward or shoreward depositional facies cannot yet be correlated with definite formations. For convenience in reference, the old and new formation names are listed in the accompanying table.

parishes, and its No. 9 Louisiana Central Lumber Co., sec. 13, T. 10 N., R. 2 E., a west offset to the deep test, was started and completed as the discovery well of the field on March 26, 1940, flowing 14 bbl. per hour of 31° gravity oil from perforations at 2270 to 2276 ft., after testing lower sands down to 2983 ft.

Meanwhile, the No. 1 Goodpine Oil Co. continued drilling to a depth of 8997 ft., penetrating approximately 2285 ft. of Wilcox formation, 696 ft. of Midway, 1926 ft. of Upper Cretaceous, and 2458 ft. into the Lower Cretaceous. Evidently it stopped somewhere in the lower Glen Rose, as some anhydrite was reported between 7800 and 8050 ft., although there was no thick, massive bed of anhydrite. This well was finally completed as the second oil producer in the field at 2267 to 2272 ft., in the same sand as the No. 9 Louisiana Central Lumber Co.

Divisions of Lower Cretaceous and Underlying Beds in North Louisiana

Old Name	New Name
Lower Cretaceous	Lower Cretaceous
Washita group	Washita group
Fredericksburg group	Fredericksburg group
Trinity group	Trinity group
Paluxy formation	Paluxy formation
	Glen Rose subgroup
Upper Glen Rose formation	Mooringsport formation
Middle Glen Rose formation	Ferry Lake anhydrite
Lower Glen Rose formation	
Rodessa member	Rodessa formation
Pine Island member	Pine Island formation Sligo formation
Travis Peak formation	Hosston formation
Lower Mesozoic?	Jurassic
Cotton Valley formation	Cotton Valley formation
Buckner formation	Buckner formation
Smackover limestone	Smackover formation
Eagle Mills red beds and contemporaneous rock salt	Eagle Mills red beds and contemporaneous rock salt Morehouse formation
Paleozoic	Paleozoic

New Fields

Olla Field.—The Arkansas Fuel Oil Co. and H. L. Hunt's No. 1 Goodpine Oil Co., sec. 18, T. 10 N., R. 3 E., La Salle Parish, about 4 miles southeast of Olla and 5 miles east of the Urania oil field, was started as a deep test in 1939, and in December of that year had a large blowout of gas with salt water and a showing of oil while drilling a little below 3000 ft. The location was made on the basis of subsurface structure, checked by geophysical surveys. The Placid Oil Co., controlled by H. L. Hunt, had been drilling a series of shallow tests on a large acreage in La Salle and adjoining

The field was soon extended to cover an area 6 miles north and south by 2 miles east and west. At the end of the year there were 93 oil wells and 1 gas well in the field, besides 3 wildcat gas wells several miles north, northeast and south of oil production. Oil was being produced from six different sand members or lenses, collectively known as the "Olla zone," between 590 and 800 ft. below the top of the Wilcox formation. Productive areas of the various sands overlap to some extent, but so far only one well has been drilled on each 40

TABLE 1.—*Oil and Gas Production in North Louisiana*

Line Number	Field, *Parish*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
1	Bear Creek, *Bienville*	1937	0	2,500	0	0
2	Bellevue, *Bossier*	1921	1,360	160	10,492,435	182,550
3	Bethany—Waskom, *Caddo*[1]	1916	20	15,000	0	0
4	Caddo, *Caddo*[2]	1904	32,500	5,000	159,330,365	2,809,945
5	Carterville, *Bossier*	1927	720	2,720	1,602,447	27,937
6	Clayton, *Concordia*	1931	0	60	0	0
7	Converse, *Sabine*	1932	2,000	0	2,307,015	192,505
8	Cotton Valley, *Webster* (total)		14,000		28,755,185	5,124,535
9	Shallow, gas and heavy oil	1922	2,600	6,600	14,942,500	1,060
10	Holloway, light oil	1936	2,000	40	4,372,066	1,031,795
11	Bodcaw and "D," light oil	1938	3,000	0	4,412,906	2,680,230
12	Bodcaw and "D," gas-condensate	1937	0	11,000	5,027,713	1,411,450
13	De Soto-Red River, *De Soto, Red River*	1912	11,000	3,300	58,097,490	371,105
14	Driscoll, *Bienville*	1936	0	1,000	0	0
15	Elm Grove, *Bossier, Caddo*	1916	320	14,600	3,665,490	112,580
16	Epps, *East Carroll, West Carroll*	1928	0	1,200	0	0
17	Haynesville, *Claiborne*	1921	7,480	0	70,912,660	982,810
18	Holly, *De Soto*	1930	80	160	991,465	28,545
19	Homer, *Claiborne*	1919	3,020	0	70,284,245	1,021,135
20	Lake Bistineau, *Bienville*	1916	0	3,200	0	0
21	Lisbon, *Claiborne, Lincoln*: oil	1936	7,500	0	8,911,320	1,490,355
22	Gas-condensate	1939	0	1,000	*x*	*x*
23	Logansport, *De Soto*	1938	0	8,000	0	0
24	Monroe, *Morehouse, Ouachita, Union*	1916	0	270,000	0	0
25	Nebo, *LaSalle*	1940	400	0	52,100	52,100
26	Olla, *La Salle*	1940	4,600	*x*	972,530	972,530
27	Pleasant Hill, *Sabine*	1927	800	0	1,590,385	33,815
28	Richland, *Richland*	1926	0	49,280	0	0
29	Rodessa, *Caddo*	1930	9,400	7,800[3]	67,963,140	6,904,220
30	Ruston, *Lincoln*	1937	0	160	0	0
31	Sarepta, *Bossier, Webster*	1922	570	1,120	1,645,587	60,998
32	Shongaloo, *Webster*: shallow	1921	70	5,680	121,807	5,692
33	Deep	1938	80	1,000	107,689	20,043
34	Shreveport, *Caddo*	1938	2,500	240	3,527,000	1,548,125
35	Sibley, *Webster*	1936	0	640	0	0
36	Simsboro, *Lincoln*	1935	0	320	0	0

[b] Footnotes to column heads and explanation of symbols are given on p. 256.
[1] Includes the Louisiana part of the Bethany and Waskom fields; also Blanchard, Longwood, Greenwood, Cedar Grove, Spring Ridge and old Cross Lake gas areas.
[2] Includes Mooringsport, Trees City, Pine Island, Hosston, Gilliam, Dixie and Vivian areas.
[3] Most Rodessa acreage produces both oil and gas; classification of wells depends on gas-oil ratios and is often changed.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil	
	To End of 1940	During 1940[5]	Completed to End of 1940	During 1940		End of 1940			Number of Wells		Initial	Avg. at End of 1940		Gravity, A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
				Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift					
1	1,190	504	5	0	0	5	0	0	0	0	2,660 2,925	2,620 2,925			
2	2,553	90	423	1	3	8[6]	147	2	0	147	y	0	SR	19	0.80
3	19,753	1,000	182	1	0	y	0	42	0	0	1,880 2,380	y 2,253			
4	140,578	1,500	4,667	279	65	y	1,465	49	0	1,465	y	y	SR	25 40	0.50
5	17,071	20	155	0	0	y	16	0	0	16	1,250	0		42	0.27
6	11	0	1	0	0	1	0	0	0	0	630	620			
7	102	100	192	11	6	y	82	0	0	82	y	y		42	0.15
8	149,847	21,043	447	18	4	3	85	80	69	16					
9	x	x	279	0	4	0	0	0	0	0	y	y		25	0.25
10	x	x	51	4	0	3	46	2	30	16	2,525	y		48	0.12
11	x	x	39	14	0	0	39	0	39	0	3,930	3,500		45	0.15
12	x	x	78	0	0	0	0	78	0	0	3,930	3,500		64	0.10
13	66,359	1,232	1,439	7	16	y	129	26	0	129	y	y	SR	40	0.25
14	8,963	2,892	4	0	0	0	0	4	0	0	2,375 2,830	1,608 2,072			
15	194,078	1,000	249	1	6	y	38	41	0	38	y	20–100		29	0.40
16	7,627	1,242	4	0	0	0	0	4	0	0	1,060	800			
17	3,809	275	766	0	3	y	284	0	0	284	y	y		36	0.40
18	146	10	15	0	0	y	4	2	0	4	y	y		37	0.22
19	6,572	229	633	0	6	y	349	0	0	349	y	y		36	0.63
20	10,251	7,710	24	4	0	0	0	14	0	0	2,310	2,000			
21	3,256	280	266	0	1	43[7]	184	0	33	151	2,000	700		34	1.10
22	x	x	2	1	0	0	0	2	0	0	2,900	y		63	0.10
23	0	0	2	1	0	2	0	0	0	0	2,423 2,880	2,423 2,880			
24	2,814,051	192,509	1,368	55	0	144	0	1,107	0	0	1,020	50–950			
25	22	22	7	7	0	0	7	0	7	0	1,550	1,500		39	0.15
26	500	500	94	94	0	0	93	1	79	14	1,000	800		31	0.16
27	359	100	62	0	0	y	29	0	0	29	y	y		40	0.30
28	450,618	3	313	0	5	0	0	0	0	0	1,125	100			
29	338,613	58,587	504	5	17	40	336	105[3]	150	186	2,780	980[8] 147		44 65	0.10
30	0	0	1	0	0	1	0	0	0	0	2,134	2,134			
31	25,603	10	44	0	0	y	6	0	0	6	y	y		25	0.32
32	72,334	200	91	0	2	0	1	0	0	1	y	y		29	0.35
33	x	x	3	0	1	0	0	2	0	0	4,255	y		64	0.10
34	6,052	3,000	56	5	6	1	49	0	30	19	2,602	500		44	0.20
35	1,194	855	4	0	0	0	0	4	0	0	2,400	1,940			
36	6,322	1,104	2	0	0	0	0	2	0	0	2,100 2,620	536 2,489			

[5] Gas production totals by parishes, including casinghead gas and gas used in lease operations, were supplied by the Louisiana Department of Minerals, J. Huner, Jr., State Geologist. Distribution by fields is estimated on best available information. The Rodessa Operators Committee estimates Rodessa gas production in 1940 as 75,927 million cu. ft. (55,054 million to pipe lines and 20 873 millions to air); cumulative total to Dec. 25, 1940, as 542,085 million cu. ft. (289,727 million to pipe lines and 252,358 million to air).

[6] These eight wells drilled for water injection.

[7] Includes 13 former oil wells used for gas injection.

[8] Weighted average, Dees-Young 980 lb., Gloyd, 147 lb.

TABLE 1.—(*Continued*)

	Producing Formation								Deepest Zone Tested to End of 1940	
					Depth, Avg. Ft.					
Line Number	Name	Age[e]	Character[f]	Porosity[g]	Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	Sligo Hosston	CreL	OL, S	Por	6,665 7,320	6,695 7,879	y	A	Hosston	8,017
2	Nacatoch Rodessa	CreU CreL	S	Por	360 1,010	400 1,035	25	AF	Cotton Valley	6,137
3	[9]	CreU CreL	S, OL	Por	[9]	1,000– 6,100	y	A	Cotton Valley	9,244
4	[10]	CreU CreL	S, C, OL	Por	[10]	1,000– 4,000	y	Af	Igneous below Jur. salt	11,419
5	Buckrange Tokio	CreU	S	Por	3,050 3,140	3,060 3,150	9	A	Cotton Valley	10,066
6	Jackson	Eoc	S	Por	1,415	1,438	25	N	Midway	6,800
7	Saratoga-Annona Paluxy, Rodessa	CreU CreL	C L	Fis Por	1,617 3,150	1,922 3,232	x	Af	Hosston	8,929
8								A	Cotton Valley	9,198
9	Buckrange Rodessa	CreU CreL	S S, A, OL	Por	2,532 4,350	2,547 4,652	11 x	A	Cotton Valley	9,198
10	Hosston	CreL	S	10	5,692	5,987	15	AL	Cotton Valley	9,198
11	Cotton Valley	Jur	S	17	8,570	8,650	40	A	Cotton Valley	9,198
12	Cotton Valley	Jur	S	17	8,270	8,650	40	A	Cotton Valley	9,198
13	[11]	CreU CreL	S, C	Por	[11]	825– 3,500	y	AF	Pine Island	6,488
14	Rodessa Hosston	CreL	OL S	15	5,862 7,160	5,880 7,216	18 50	A	Hosston	7,693
15	Nacatoch Ozan, Tokio	CreU	S	Por	804 2,469	840 2,496	y	A	Cotton Valley	8,647
16	Monroe gas rock	CreU	LS	Por	2,336	2,344	8	D	Igneous	3,142
17	Buckrange	CreU	S	Por	2,655	2,680	25	A	Smackover	11,270
18	Eagle Ford	CreU	S	Por	2,538	2,581	11	NL	Paluxy	3,373
19	Nacatoch Buckrange	CreU	S	Por	1,280 2,040	1,345 2,065	63	AF	Cotton Valley	4,504
20	Ozan, Tokio, Sligo Cotton Valley	CreU CreL Jur	S, OL	Por	5,100 8,400	5,200 8,532	50	Af	Cotton Valley	8,532
21	Sligo	CreL	O	5–20	5,275	5,300	12	AL	Jurassic salt	11,834
22	Cotton Valley	Jur	S	Por	8,444 8,766	8,464 8,806	20	AL	Jurassic salt	11,834
23	Rodessa Sligo	CreL	OL	20 12	4,876 5,980	5,032 6,271	50 13	A	Hosston	6,271
24	Monroe gas rock	CreU	LS	23	2,145	2,205	50	A	Morehouse below Jur. salt	10,475
25	Wilcox	Eoc	S	30	3,353 3,791	3,900	10	AL	Wilcox	4,364
26	Wilcox	Eoc	S	30	2,180 2,410	2,200 2,427	15	AL	L Glen Rose	8,997
27	Paluxy	CreL	L, S	Por	3,175	3,237	16	Nf	Mooringsport	5,063
28	Monroe gas rock, Tokio, Rodessa	CreU CreL	S, LS	Por	2,349	2,447	76	A	Cotton Valley	9,986
29	Rodessa	CreL	S, L, LS, OL	5–35	5,560 6,075	5,600 6,100	5–80	AF	Jurassic salt	11,486
30	Sligo	CreL	OL	Por	5,316	5,822	10	A	Hosston	5,822
31	Buckrange	CreU	S	Por	2,681	2,700	11	A	Rodessa	5,120
32	Buckrange	CreU	S	Por	2,665	2,680	12	A	Cotton Valley	10,462
33	Cotton Valley	Jur	S	Por	9,000	9,680	20	A	Cotton Valley	10,462
34	Sligo	CreL	OL	Por	5,550	5,581	15	A	Hosston	6,025
35	Rodessa	CreL	OL	Por	5,570	6,112	40	A	Cotton Valley	10,383
36	Rodessa Hosston	CreL	OL, S	Por	5,282 6,451	6,301 6,576	30	A	Hosston	7,023

[9] Different areas produce gas from Nacatoch at about 1000 ft.; Buckrange, 1950; Tokio-Paluxy, 2300 to 2550; Rodessa, 4650; Sligo, 5850; Hosston, 5900 to 6100.

[10] Production from Nacatoch at about 1000 ft., Saratoga-Annona chalk, 1350 to 1750; "Blossom," 1825; Tokio-Paluxy 2250 to 2400; and at Pine Island, from Rodessa formation, 2800 to 3000; Sligo, 3700 to 3800; Hosston, 3900 to 4000.

[11] Production from Nacatoch at about 800 ft.; Saratoga-Annona chalk, 1400; Eagle Ford-Paluxy, 2600; gas from Paluxy, 3500.

acres, each well being completed in the sand that seems best at that particular location. Individual sands are thin, and the soft formations and intimate association of oil, gas and salt water in each sand have caused considerable difficulty in completion and maintenance of wells. All wells have been completed through gun perforations in the casing, and it is commonly necessary to squeeze cement through other perforations above and below the producing sand to shut off gas and salt water. All wells produce some salt water with the oil, as even the best oil sands contain considerable connate water.

Most wells were completed flowing, but some needed pumping or gas lift from the start. Almost all are able to make their allowable production, which is 100 bbl. per day for a well on 40 acres. The oil is considered of premium grade because of low sulphur content and high antiknock quality of gasoline produced.

The structure is an irregular anticline, with a closure of about 100 ft. to the northwest of the main dome on the sands of the Olla zone. It is less pronounced on the top of the Wilcox formation, which is an unconformable contact with the overlying Cane River formation.

This discovery opened the first production of any importance in the middle portion of the thick Wilcox formation, as the few fields previously opened in that formation produced from sands at or very near the top, and wildcat wells were seldom carried more than 200 or 300 ft. into the Wilcox. This opens for retesting the entire belt where the Wilcox formation lies within reach of the drill, not only in north and central Louisiana, but all the way from Georgia to Mexico, and means that structures of low relief will be sought and tested as well as salt domes.

Nebo Field.—H. L. Hunt's No. A-1 Goodpine Oil Co., in sec. 10, T. 7 N., R. 3 E., La Salle Parish, 6 miles south of Jena, was completed on Sept. 21, 1940, producing 48 bbl. per day of 39° gravity oil with 6,000,000 cu. ft. of gas from perforations at 3353 to 3362 ft. The total depth was 3695 ft., and several lower sands had been tested first. Subsequent wells were better, producing more oil with lower gas ratios, but difficulties were encountered, as at Olla, in shutting off gas and salt water.

TABLE 1.—(*Continued*)

Line Number	Field, *Parish*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
37	Sligo, *Bossier*	1922	800	12,000	1,654,160	716,265
38	Sugar Creek, *Claiborne*	1931	400	4,000	578,125	217,970
39	Sutherlin-Spider, *De Soto*	1935	0	320	0	0
40	Urania, *Grant, LaSalle, Winn*	1925	3,700	0	25,155,050	893,465
41	White Sulphur, *La Salle*	1928	80	0	12,290	0
42	Zwolle, *Sabine*	1928	7,620[4]	0	15,533,780	612,535
43	Total		100,020	421,160	534,263,760	24,381,760

[4] Allowing 20 acres per producing well, although Zwolle production is scattered over a much larger area.

By the end of the year there were seven oil wells, producing from six different sands in the "Nebo zone" at depths of 3350 to 3800 ft., or 900 to 1300 ft. below the top of the Wilcox formation. The producing area and structural details are still undefined, but it is a field of the same type as Olla. There is a marked unconformity at the top of the Wilcox formation, and structural uplift is greater in the producing zone than in the overlying formations.

Extensions and Developments

Caddo Field.—A notable increase in activity occurred in the old Caddo field in 1940, and this field accounted for more than half of the producing wells drilled in north Louisiana, with 276 oil wells, 3 gas wells and 44 dry holes. Of the oil wells, 233 were completed in the Saratoga-Annona chalk at depths of 1350 to 1750 ft., while 5 oil wells and 15 dry holes were drilled in the Vivian extension in T. 22 N., R. 16 W. No deep tests were drilled except the Stanolind Oil & Gas Company's No. 131 Dillon Heirs, sec. 14., T. 21 N., R. 15 W., completed in a shallow sand in January 1940, after drilling into igneous rock below the Jurassic salt at a total depth of 11,419 ft. (more fully described in the report for 1939, *Trans.* A.I.M.E., 1940, **136**, 314.)

As a result of new drilling, oil production increased about 250,000 bbl., which is remarkable for a field 37 years old.

Cotton Valley Field.—Most of the drilling at Cotton Valley was in the deep oil-producing belt around the flanks of the structure. There were eight oil wells and one gas-condensate well in the "D" sand; four oil and one gas-condensate in the Bodcaw sand; four oil wells in the Holloway (5700 ft.) sand. Five dry holes were abandoned below the Holloway and one Bodcaw sand test was dry. During the year the unitization of leases and mineral ownerships was completed and construction work was started on the largest gas-cycling plant in the world, at an approximate cost of $2,000,000, to handle the very rich gas from the 8100 to 8500-ft. sands.

Lisbon Field.—No new Sligo (Pettit zone) wells were drilled in 1940, but E. T. Oakes et al.'s No. 1 C. C. Whitman, an old producer, was deepened from 5277 to 5428 ft. and recompleted in November, producing 81 bbl. per day of 42° gravity oil with 500,000 cu. ft. of gas from perforations at 5401 to 5405 ft. as the discovery well in a

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operations[d]	Character of Oil	
	To End of 1940	During 1940[b]	Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[e]	End of 1940: Producing Gas[c]	Number of Wells: Flowing	Number of Wells: Artificial Lift	Initial	Avg. at End of 1940		Gravity, A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
37	110,378	22,856	137	15	10	1	30	61	10	20	1,890 2,200	1,650 2,000		42	0.16
38	51,264	7,297	22	5	1	0	8	13	8	0	1,800 2,310	350 1,650		39	0.17
39	221	0	5	0	0	2	0	0	0	0	1,200	800			
40	6	0	522	9	0	y	262	0	0	262	y	0		18	0.30
41	0	0	12	0	0	0	0	0	0	0	y	0		20	y
42	223	43	381	5	8	y	60	0	0	60	y	0		40	0.10
43	4,509,926	326,213	13,104	524	160	251	3,664	1,561	386	3,278					

new sand near the top of the Hosston formation. Two other old wells deepened to the same horizon were dry.

Gas from the Lisbon Exploration Company's No. 1 Vaughn, completed in the Cotton Valley formation in 1939, was used for repressuring the Pettit zone, with 13 former producing wells used for injection. This has at least retarded the rapid decline in production, and the average bottom-hole pressure built up from about 400 to 700 lb., although there are local variations from 150 to 1900 lb. in different parts of the field.

J. D. Caruthers, Trustee's No. 1 Simmons Unit, sec. 2, T. 20 N., R. 5 W., was completed in December as the second gas-condensate producer from the Cotton Valley formation, making 160 bbl. per day of 53° gravity condensate with 2,000,000 cu. ft. of gas from 8766 to 8806 ft., total depth 9016 ft. The producing sand is about 950 ft. below the top of the Cotton Valley, and is several hundred feet lower than that in the previous deep well.

The Union Producing Company's No. A-1 Meadows, sec. 18, T. 21 N., R. 4 W., was drilling below 10,000 ft. at the end of 1940 and has since been completed as the deepest hole and the first Smackover limestone producer in north Louisiana. This location is 2 miles north of the Lisbon oil-producing area, but is structurally higher and believed to be near the top of the large domelike structure. This well penetrated about 2300 ft. of Hosston formation, 2830 ft. of Cotton Valley, with Buckner formation absent, and 1579 ft. of Smackover formation, of which the upper 600 ft. is more or less porous limestone. The top of the Smackover is at 10,250 ft., and rock salt was cored from 11,829 to 11,834 ft., the total depth. Casing was set in the Smackover and perforated with 654 shots between 10,148 and 10,398 ft. On tests, the well has produced 650 bbl. per day of 55.9° gravity condensate through ⅜-in. choke with gas-oil ratio of less than 10,000 cu. ft. per barrel. Closed-in pressure is more than 5000 lb. per sq. inch.

Logansport Field.—The second deep test drilled on the Louisiana side at Logansport, the Union Producing Company's No. B-1 Garrett, sec. 33, T. 12 N., R. 16 W., was completed in November, producing 68,000,000 cu. ft. of gas with considerable condensate from an oölitic limestone at 5982

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
37	[12]	CreU, CreL	S, OL	Por	[12]	850–5,200	30	A	Hosston	6,112
38	Rodessa, Sligo, Hosston	CreL	OL, S, LS	18 Por	4,370 5,750	4,400 5,800	13 50	A	Cotton Valley	10,759
39	Paluxy	CreL	S	Por	2,840	2,850	10	AL	Pine Island	5,930
40	Wilcox	Eoc	S	Por	1,520	1,530	9	AU	Tokio	6,463
41	Jackson	Eoc	S	Por	794	804	9	NF	Wilcox	2,435
42	Saratoga-Annona, Paluxy	CreU, CreL	C, L	Fis	2,100	2,500	x	Af	L Glen Rose	7,155
43										

[12] Production from Nacatoch at about 850 ft.; Buckrange, 1725; Tokio, 2450; Paluxy 2750 and 3100; Rodessa, 4100 to 4275, Sligo, 5100 to 5200.

to 5995 ft., total depth 6271 ft. This well found the Rodessa member at 4940 to 5040 ft. too tight, and was drilled deeper to open a new producing formation for the field, correlated with the Pettit member of the Sligo formation.

At the end of the year the Southern Production Co. had started a drilling program and Southern Natural Gas Co. was preparing to build a pipe line from Logansport to connect with its Birmingham and Atlanta line at Monroe, while United Gas Pipe Line Co. was laying a short line to tie in with its system in Texas. Therefore this field, which is one of the most important deep gas reserves of the state, will have considerable development in 1941.

Deep Gas Fields.—Activities in other deep gas fields were normal and no exceptionally deep tests were drilled. At Lake Bistineau, Bienville Parish, four gas wells were completed in the Sligo formation, together with one dry hole. At Sligo, Bossier Parish, 13 oil wells were completed in the 3100-ft. sand, but there were only two deep gas wells, one each in the Rodessa and Sligo formations. In July 1940 the United Gas Pipe Line Co. put in operation a gasoline plant of 60,000,000-cu. ft. daily capacity at Koran in southern Bossier Parish, to handle gas from both Lake Bistineau and Sligo fields.

In the Sugar Creek field, Claiborne Parish, five good oil wells were completed in the Sligo-Hosston contact zone, all on the northeastern flank of the gas field, but no gas wells were drilled. In the Sibley field, Webster Parish, only one dry hole was drilled, limiting the producing area on the south.

In the Bethany-Greenwood-Waskom area of Caddo Parish no deep tests were drilled, but the Delta Drilling Company's No. 1 Dunn, sec. 24, T. 17 N., R. 16 W., near the village of Greenwood, blew out and was completed as a gas well at 2551 ft. This extends the old Tokio-Paluxy gas-producing area to the southeast.

TABLE 2.—*Summary of Drilling Operations in North Louisiana*

Important Wildcats Drilled in 1940

	Parish	Location			Total Depth, Ft.	Surface Formation	Deepest Horizon Tested	Drilled by
		Sec.	Twp.	Rge.				
1	Bienville	29	18 N	6 W	7,502	Claiborne	Hosston	H. Hanbury et al.
2	Bossier	24	16 N	12 W	8,647	Wilcox	Cotton Valley	Gulf Refining Co.
3	Caddo	24	17 N	16 W	2,551	Wilcox	Tokio	Delta Drilling Co.
4	Caddo	14	21 N	15 W	11,419	Wilcox	Igneous below Jurassic salt	Stanolind Oil & Gas Co.
5	Catahoula	12	9 N	7 E	9,215	Pleistocene	Upper Glen Rose	Continental Oil Co.
6	Claiborne	2	20 N	5 W	9,016	Claiborne	Cotton Valley	J. D. Caruthers, Tr.
7	Claiborne	2	20 N	5 W	5,428	Claiborne	Hosston	E. T. Oakes et al.
8	Claiborne	18	21 N	4 W	11,834	Claiborne	Jurassic salt	Union Producing Co.
9	Claiborne	15	23 N	8 W	11,270	Claiborne	Smackover	Ohio Oil Co. et al.
10	Concordia	41	8 N	10 E	6,800	Pleistocene	Midway	K. Hughes et al.
11	De Soto	33	12 N	16 W	6,271	Wilcox	Hosston	Union Producing Co.
12	Franklin	35	14 N	9 E	5,413	Pleistocene	Ozan	H. L. Hunt
13	La Salle	13	10 N	2 E	2,983	Jackson	Wilcox	Placid Oil Co.
14	La Salle	18	10 N	3 E	8,997	Jackson	Lower Glen Rose	Arkansas Fuel Oil Co. & H. L. Hunt
15	La Salle	19	11 N	3 E	5,097	Jackson	Ozan	Placid Oil Co.
16	La Salle	32	11 N	3 E	2,546	Jackson	Wilcox	O. K. Allen, Jr. et al.
17	La Salle	25	9 N	2 E	4,020	Vicksburg	Wilcox	Petersen Petroleum Co.
18	La Salle	10	7 N	3 E	3,695	Citronelle	Wilcox	H. L. Hunt
19	Morehouse	8	22 N	4 E	10,475	Claiborne	Morehouse	Union Producing Co.
20	Madison	33	18 N	12 E	5,545	Pleistocene	Hosston ?	Gulf Refining Co.
21	Rapides	1	1 N	1 W	7,650	Citronelle	Wilcox	Rantex Oil Corp.
22	Sabine	30	4 N	12 W	7,562	Cockfield	Fredericksburg	Shell Oil Co.
23	Webster	11	17 N	9 W	6,075	Claiborne	Rodessa	W. C. Feazel

Other Old Fields.—In the shallow Bellevue field, Bossier Parish, only one oil well was completed. The Tide Water Associated Oil Co. drilled eight injection wells to the 400-ft. Nacatoch sand on a lease in sec. 10, T. 19 N., R. 11 W., in preparation for starting the first water-flooding project in Louisiana.

The first deep test in the Elm Grove oil and gas field, an apparently favorable structure, was drilled in 1940. The Gulf Refining Company's No. 20 C. B. Hodges, sec. 24, T. 16 N., R. 12 W., Bossier Parish, was drilled to 8647 ft., or about 700 ft. into the Cotton Valley formation. There were some gas and salt water in the Rodessa zone, but the deeper formations were all tight and dry, and the test was plugged back and completed as a small oil well in the shallow sand at 1562 feet.

Another important deep test was drilled near the center of the Haynesville oil field, Claiborne Parish. The Ohio Oil Company's No. 15 G. W. Taylor Acct. 1, sec. 15, T. 23 N., R. 8 W. was completed as a dry hole at a total depth of 11,270 ft., having penetrated about 1800 ft. of Hosston formation, 3370 ft. of Cotton Valley, 406 ft. of Buckner and 312 ft. into the Smackover. The top of the Smackover formation was at a depth of 10,958 ft. The top 150 ft. of this formation is limestone with some porosity, but the remainder is mostly black shale. This well found the Buckner and Smackover formations typically developed, and this fact, together with the great thickness of the

Table 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.	Remarks
	Oil, U. S. Bbl.	Gas, Millions Cu. Ft.			
1					Dry. Gibsland area
2	10		Pumping		Elm Grove field. Deep formations dry, perforated 1560 to 1562 ft.
3		3¼		1,100	Greenwood area. Extends gas field
4		1½	2″	889	Pine Island area, Caddo field. Deep formations dry, perf. 3903 to 3938 ft. in Hosston
5					Dry. Deepest test in parish
6	160 condensate	2	⅜	C.P. 950	Lisbon field. Second producer in Cotton Valley, new producing zone. Perf. 8766 to 8806 ft.
7	81	½	¼	C.P. 900	Lisbon field. New producing sand in Hosston. Perf. 5401 to 5405 ft.
8	650 condensate	8	⅜	5,000	Lisbon field. Completed March 1941, first Smackover production in La. Perf. 10,148 to 10,398 ft.
9					Dry. Haynesville field, deepest test
10					Dry. Clayton area. Deepest test in parish
11	Condensate	68	Open	2,880	Logansport field. New producing zone in Sligo. Perf. 5980 to 5997 ft.
12					Dry
13	336		¼	1,000	Olla field. Discovery well. Perf. 2270 to 2276 ft.
14	177		¼	1,000	Olla field. Second producer and deepest test. Perf. 2267 to 2272 ft.
15		20	Open	1,100	Gas discovery, north of Olla field. Perf. 2475 to 2485 ft.
16		5	Open	900	Gas discovery, northeast of Olla field. Perf. 2164 to 2167 ft.
17		3	Open	1,400	Gas discovery, south of Olla field. Perf. 3162 to 3164 ft.
18	48	6	¼	1,500	Nebo field. Discovery well. Perf. 3353 to 3362 ft.
19		2½	Open	1,000	Monroe field. Stratigraphically deepest test in La. Deep formations dry, perf. 2163 to 2225 ft.
20					Dry. Deepest test in parish
21					Dry
22					Dry. First deep test in south end of parish
23					Dry. Limits Sibley field on south

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	51	19
Number of oil wells completed during 1940	449	2
Number of gas wells completed during 1940	72	4
Number of dry holes completed during 1940	80	55

Cotton Valley, shows that deep tests previously drilled at Shongaloo and Sugar Creek and supposed to have reached the "Smackover equivalents" really stopped in the Cotton Valley or upper Buckner.

Only four oil wells and one gas well were completed in the Rodessa field, and five oil wells in the Shreveport field, which virtually complete the development of these Caddo Parish areas. At Rodessa pressure has dropped very low in some parts of the field. In January 1941, the total salt water produced was estimated at 11,327 bbl. per day with 15,748 bbl. of oil. Wells are continually being worked over by plugging back, reperforating and acid treatments, changing from one producing member to another and from oil to gas or vice versa. Salt water is encroaching in the Shreveport field, and six edge wells have been abandoned after a productive life of 2 years or less.

Oil wells completed in other old fields included 5 in De Soto-Red River, 9 in Urania, 11 in Converse and 5 in Zwolle. In the Homer field only one repressuring well was drilled, but production has increased each year since 1937 in this old field, as a result of the repressuring program. Drilling continued in the Monroe gas field, where 55 producing wells were completed; 12 in Morehouse Parish, 10 in Ouachita and 33 in Union. The deep test drilled by the Union Producing Co., although not officially completed until 1940, was discussed in the report for 1939 (*Trans.* A.I.M.E., 1940, **136**, 314).

Wildcat Drilling.—In Caddo Parish the only deep wildcat tests of any importance were three dry holes from 5200 to 6500 ft. deep in the Spring Ridge area, east of the Bethany gas field. In Catahoula Parish, the Continental Oil Company's No. 1 Tensas Delta Lumber Co., sec. 12, T. 9 N., R. 7 E., 6 miles southwest of Sicily Island, was drilled to 9215 ft. and into the Lower Cretaceous, probably stopping in the upper Glen Rose. It is by far the deepest well in the parish, and was located on geophysical evidence, but showed no abnormal structure. Porous beds are notably lacking throughout the Upper Cretaceous section.

In Claiborne Parish, the Skelly Oil Company's No. 1 Volentine, sec. 31, T. 20 N., R. 6 W., 2 miles north of Athens, was testing at a total depth of 6507 ft. at the end of the year, and showing up as the discovery of a gas-condensate field from either the Sligo or upper Hosston formation.

In Madison Parish, the Gulf Refining Company's No. 1 E. Sondheimer Co., sec. 33, T. 18 N., R. 12 E., 7 miles northwest of Tallulah, was dry in Lower Cretaceous red beds 800 ft. below the base of the Ferry Lake anhydrite at a total depth of 5538 ft. This test was important because it found a normal anhydrite section, and gave the first proof that the belt of deposition of the Lower Cretaceous formations of northwest Louisiana swings around south of the Monroe-Richland uplift, then north up the Mississippi embayment for a considerable distance and into Mississippi. The same formations were subsequently found in at least one well in Mississippi.

In Sabine Parish, the Shell Oil Company's No. 1 Pickering Lumber Co., sec. 30, T. 4 N., R. 12 W. was drilled to 7564 ft. and stopped in a Lower Cretaceous limestone formation, believed to be Fredericksburg. This is the first deep test drilled in the extreme southern part of the parish, where the formations dip steeply south into the Gulf Coast geosyncline. It penetrated probably the greatest known thickness of Wilcox and Midway formations, 3500 and 1067 ft., respectively, but the entire thickness of Upper Cretaceous beds is only 1693 feet.

The La Salle Parish discoveries naturally stimulated wildcat drilling along the "Wilcox trend," which may be roughly described as the belt where the top of the Wilcox formation is to be expected between 1000 and 10,000 ft. below the surface. A total of 35 wildcat dry holes were com-

pleted in 1940 on this trend in the 11 parishes of Avoyelles, Caldwell, Catahoula, Concordia, Franklin, Grant, La Salle, Madison, Rapides, Tensas and Winn. The deeper and more important of these tests have already been mentioned, or are included in Table 2. No tests were drilled on interior salt domes during the year.

Conclusion

No great change is to be expected in total oil production in 1941, as development of newer fields should balance the decline in older ones.

Many more wildcat wells will be drilled along the Wilcox trend in north central Louisiana, which probably will lead to discovery of new oil fields. This exploration will require several years, because of the great difficulty in locating favorable structures, particularly areas of favorable sand conditions, by any method except subsurface geology.

Outlets have been or are being provided for most of the deep gas fields, and demand for gas is increasing, so these fields will be developed more rapidly than during other recent years. The discovery of gas and condensate production in the Smackover formation at Lisbon gives the first real encouragement to very deep drilling, but the number of wells drilled to that horizon will not be large, as cost of drilling is almost prohibitive to any except major operators.

Acknowledgments

Oil-production statistics were supplied chiefly by the Scouting Department of the Louark Producing Co. Other information has been obtained from most of the geologists, scouts and petroleum engineers in the Shreveport area.

Petroleum Developments in Southern Louisiana in 1940

By J. Brian Eby,* Member A.I.M.E.

The Gulf Coast of southern Louisiana during the year of 1940 was subjected to an extensive exploration and development campaign, as a result of which 16 oil fields and about 38 new producing sands were found. Although this record of discovery appears in keeping with the rate of 1939 actually in amount of new proven reserves, it may fall short of that of the previous year. Only five or six of the discoveries rated as first-class or important fields at the close of the year.

The most prominent new fields opened during the year were Neale field in Beauregard Parish, the West Cote Blanche field in St. Mary Parish, the Stella field and the West Bay field in Plaquemines Parish, and the Lake Salvador field in St. Charles Parish. There were many important oil-sand discoveries in proven fields, such as in the Bayou Perot field, the Golden Meadows field, the Iowa field, West Lake Verrett field, and the Venice field. During the year, 1047 wells were drilled in southern Louisiana, of which 768 were completed as oil-producing wells, 17 as gas wells and 262 as dry holes.

The Neale field in northwest Beauregard Parish is considered one of the most important discoveries of the year. The field centers around the north half of sec. 26, T.3 S., R.11 W., just north of the town of Neale. It was discovered by the Atlantic Refining Co., using reflection seismograph to locate the structure. Production was found in the second well drilled in the Wilcox sand on the downthrown side of a fault. The structure is known as the "Tepetate" type, being similar to that of the well-known Tepetate field. There were 12 oil wells and 3 dry holes drilled during the year. The Wilcox sand in this field occurs between 8350 and 8400 ft. and averages 30 ft. in thickness.

The West Cote Blanche Bay field, in West Cote Blanche Bay, St. Mary Parish, is a 1940 discovery by the Texas Company, credited to reflection seismograph exploration. The oil is from two sands occurring at 3110 to 3140 ft. and from 4950 to 5020 ft. Four wells were drilled during the year, three oil wells and one dry hole. The deepest hole drilled reached 9491 ft. without encountering salt or dome material.

In Plaquemines Parish, south of New Orleans, the California company has a new field known as the Stella field. The sand was found at a depth of 7485 ft., and 5 ft. of perforations made a well capable of producing 486 bbl. of oil in 24 hr. through a 3/16-in. choke. The oil is 42° gravity. The discovery well was drilled to a total depth of 10,258 ft. and other producing sands were indicated. A good field appears assured, although only one well was completed within the year.

The Lake Salvador field, in the center of Lake Salvador, St. Charles Parish, gives promise of being one of the most important discoveries of the year. The discovery well was perforated at 9775 to 9800 ft. making 850 bbl. of 33.7° gravity oil daily through a 1/4-in. choke. Three wells were completed in 1940 but few details have as yet been made available.

The Gulf Oil Corporation apparently has a good field in its wildcat discovery in West Bay, Plaquemines Parish. This well found

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TABLE 1.—*Oil and Gas Production in Southern Louisiana*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
1	Abbeville, *Vermilion*	1937	140	200	577,263	174,616	2,904	1,381
2	Anse La Butte, *St. Martin*	1902	210	80	1,382,568	414,839	0	0
3	Bancroft, *Beauregard*	1938	1,000		1,931,209	1,020,000		
4	Barataria, *Jefferson*	1939	350+	0	430,120	413,075	0	
5	Bateman Lake, *St. Mary*	1937	600		692,066	304,000		
6	Bayou Blue, *Iberville*	1929	100		241,966	150,000		
7	Bayou Bouillon, *St. Martin*	1902	30		443,622	21,000		
8	Bayou Des Allemands, *St. Charles*	1937	100	20	251,024	90,529		
9	Bayou Des Glaise, *Iberville*	1940	50	0	4,300	4,300	0	0
10	Bayou Mallet, *Acadia*	1936	60	300	337,265	82,572		
11	Bayou Pigeon, *Iberia*	1940	100		98,625		0	
12	Bay St. Elaine, *Terrebonne*	1934	180		415,250	147,000		
13	Big Lake, *Cameron*	1935			68,689			
14	Black Bayou, *Cameron*	1929	100	0	8,022,000	1,024,000	3,874[2]	374[2]
15	Bosco (and Cankton), *Acadia St. Landry*	1934	1,250	0	19,794,094	1,699,918		
16	Caillou Island, *Terrebonne*	1930	600		29,941,288	2,503,000		
17	Cameron Meadows, *Cameron*	1931	320		6,571,134	710,410		
18	Chacahoula, *Lafourche*	1938	50	20	852,570	468,693	7,101	7,101
19	Chalkley, *Cameron*	1938	850	500	1,179,000	950,000	0	0
20	Charenton (Incl. West Charenton), *St. Mary*	1936	500		6,333,000	2,698,509		
21	Cheneyville, *Rapides*	1935	480	40	1,311,909	966,005	1,128	366
22	China, *Jefferson Davis*	1940	0	100	3,514[1]	3,514[1]		
23	Choctaw, *Iberville*	1931	(Rim) 150′ × 800′		189,365	20,989		
24	Convent (Vacherie), *St. James*	1938	80	0	57,000	17,000		
25	Cote Blanche, *West St. Mary*	1940	200		100,000	100,000		
26	Creole, *Cameron*	1938	100	0	1,310,760	579,058		
27	Crowley, North, *Acadia*	1937	500	0	2,817,000	1,598,000	0	0
28	Crowley, South, *Acadia*	1938	200	0	17,000	15,000	0	0
29	Darrow, *Ascension*	1932	250	0	4,304,000	748,000	0	0
30	DeLarge, *Terrebonne*	1938			107,709	59,537		
31	Delta Farms, *Lafourche*	1940			8,372	8,372		

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Distillate.
[2] Estimated.

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil	
	Completed to End of 1940	During 1940		End of 1940			Number of Wells		Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
		Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[e]	Flowing	Artificial Lift					
1	11	3	1	3	7	0	7	0	3,637[s]	3,452		46	0.1
2	63	24	0	0	32	0	20	12	Normal	y		23–27	y
3					41							43.4	
4	10	9	1	0	10	0	10	0				36.5	0.2
5					5							38	
6					13								
7					2								
8	6	2	1	0	4	1	3	1	3,200	3,000		35-45	0.2
9	1	1	1	0	0	0	0	0	y			37.7	0.13
10	5			0	5	0	5	0				30	
11	3	3	0	0	3	0	3	0				35.6	
12					7								
13	5		5	0	0	0							
14	29	0	0	5	20	0	12	8		2,100		25	0.15
15	71	0	0	0	55	2	57	0			P.M.	38.8	
16					49								
17	59	4	2	1	31		10	21					
18	8	4	1	1	7	1 gas[1]	6	1				32.5	0.14
19	20	10	0	0	17	3	17	0	y	y		36	0.12
20	180	35	5	15	160		15	145				19–37	0.2
21	38	17	5	0	31	1	28	3	2,300	2,300		44	0.15
22	1	1	0	0	0	1	1	0	±4,100	±4,100			?
23	4	0	0	2	2	0	2	0	2,450	2,450		39.3	
24	2	0	0	0	1	0	1	0	?	?	?	38	0.10
25					5		1	0	?	?		38	0.10
26	9	0	0	0	9	0	9	0				33.7	
27	35	17	0	0	35	0	35	0	y	y		35	0.17
28	3	3	0	0	3	0	3	0	y	y		35.4	0.10
29	29	5	0	0	18	0	18	0	y	y		38.5	0.12
30	1	0	0	0	1				6,250	6,250		47	
31	1	1	1	1	1	0	1	0	?				

TABLE I.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	Brookshire, Hebert, and Duhon sands	Mio	Sand	P	7,860	7,900	40	D	Oligocene	12,214
2	Patrick, Bergeron Moresi, Breaux, Patin	Pli-Mio	S	26.8	1,300 4,600	4,800	160	DS	Chickasawhay (Olig?)	9,885
3		Eoc			7,252	7,356	60	AF	Wilcox	11,018
4		Mio	S	35	8,200-A 8,750-B		A B 10–25	AF	Mio	12,222
5		Mio			8,650	10,900	(?)	AF	Miocene	11,879
6		Mio			4,854 4,900	4,864 5,000		DS	Miocene	10,140
7		Mio	Sand	27.5	424 3,198		32.5	DS	L. Oligocene	6,471
8		Mio	S	Por				DS	Salt	9,914
9	Oligocene	Olig	Sand	25	8,650	8,730	30	DS	Oligocene	9,573
10	Marginulina	Olig	Sand		6,386	7,198	20	D	Vicksburg	8,404
11		Mio	Sand	High	8,054			A	Miocene	10,000
12	Miocene	Mio	Sand	Por	6,323– 7,635– 5,520	6,390 7,755 5,643	60	DS	Miocene	10,513
13	Lower Miocene and Upper Oligocene	Mio-Olig	Sand		6,700 8,900			?	Olig. Het.	
14	Drag zone, C sand, 1-B sand, Nos. 2, 3, 4 and 5 sands	Mio	Sand No. 3	25	4,500	4,600	40	DS	Frio	8,321
15	Dis. Het. Marg.	Olig	Sand		7,830	9,118	90	D	Vicksburg	10,432
16	Miocene	Mio	Sand	Por	4,510	6,813	90	DS	Miocene	6,813
17	Miocene	Mio	Sand	30+	3,600 5,680			DS	Salt	6,955
18		Mio	Sand	31	6,178 7,174 9,245	6,300 oil 7,250 oil 9,380 Gas		DS	Miocene	9,559
19	Miocene-Oligocene	Mio-Olig	Sand	25–30	8,600 8,800 8,900 10,100	8,615 8,820 8,915 10,115	15	D	Oligocene	11,693
20		Mio	Unconsolidated sands	Por	900 7,200	900 7,200	30	DS SD	Miocene	10,690
21	Cock, Yegua & Sparta (1)	Eoc	S	25	5,660 5,890	5,725 5,910	65	DS	Salt	7,045
22		Marg-Olig	Sand	?	9,300	9,330	30	MF	9,500 ft.	9,530
23	Marginulina Frio	Olig			8,012	8,540	30	DS	8,964 ft. Frio	8,964
24		Mio-Olig	Sand	Por	8,035	8,045	10	DS	Vicksburg	10,012
25		Mio-Olig	Sand	Por	8,035	8,045	10	DS	Vicksburg	10,012
26	Miocene	Mio	Sand		5,100	6,640	100	D	Miocene	9,895
27	Miocene-Oligocene	Mio-Olig	Sand	25–30	7,200 7,700 7,900 8,100 8,800		10–30	D	Lower Oligocene	10,652
28	Miocene	Mio	Sand	25	7,100 7,600 8,900	10–12 Sand	10	D	Oligocene	10,272
29	Miocene-Oligocene	Mio-Olig	Sand	27	4,650 5,600 5,700 6,950 8,200		10–100	DS	Oligocene	10,013
30	Miocene	Mio	Sand	Por	13,208	13,333	77	AF	Miocene	13,333
31		Mio	Sand		8,795	11,374	25			11,850

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
32	Dog Lake, *Terrebonne*	1935	100		2,145,432	298,000		
33	Edgenly, *Calcasieu*	1912	215		9,532,290	99,000		
34	Elton, South, *Jefferson Davis*	1937	0	1,500	44,911[1]	20,795[1]	1,248	571
35	Elton, North, *Allen*	1939	0	640	12,144[1]	8,024[1]	258	215
36	Eola, *Avoyelles*	1939	1,740		4,492,765	3,869,982		
37	Erath, *Vermilion*	1940	20		10,000	10,000		
38	Fausse Point, *Iberia*	1926	70		71,133	23,000		
39	Four Isle, *Terrebonne*	Abandoned						
40	Garden Island Bay, *Plaquemines*	1935	300		3,513,037	1,110,000		
41	Gibson, *Terrebonne*	1937	320		3,852,364	1,325,000		
42	Gillis, *Calcasieu*	1934	1,200		19,649,617	1,567,000		
43	Golden Meadows, *Lafourche*	1938	800		4,861,294	4,112,000		
44	Grand Bay, *Plaquemines*	1938	1,000		1,738,972	1,191,000		
45	Grand Lake, *Cameron*	1939	280	0	1,051,579	924,604		
46	Gueydan, *Vermilion*	1932	35		1,165,265	146,964		
47	Gueydan, West, *Vermilion*	1938	200		386,953	252,427		
48	Hackberry (old), *Cameron*	1927	600	0	8,421,109	1,684,108	y	y
49	Happytown, *St. Martin*	1939	80	0	127,455	113,627	254	233
50	Hackberry, East, *Cameron*	1927	560		24,487,092	1,618,000		
51	Henderson, *St. Martin*	1939	100		130,000	109,000		
52	Horseshoe, *Bayou St. Mary*	1937	500		1,015,561	428,000		
53	Houma, *Terrebonne*		80		324,753	166,030		
54	Houma, South, *Terrebonne*	1938	80		324,753	166,030	1,934	686
55	Iowa Calcasieu, *Jefferson Davis*	1931	920		42,825,700	3,987,700	55,850[2]	2,525[2]
56	Jeanerette, *St. Mary*	1935	300		8,736,000	1,203,000		
57	Jefferson Island, *Iberia*	1938	140		510,229	340,000		
58	Jennings, *Acadia*	1901	630	0	76,700,717	5,549,468		
59	Jennings, South, *Jefferson Davis*	1936	0	2,300	98,303[1]	55,427	5,200	2,945
60	Kennilworth, *St. Bernard*	1935	20		83,184	75,000		
61	Lafitte, *Jefferson*	1935	2,240		22,807,100	4,600,000		
62	Lake Barre, *Terrebonne*	1929	400		16,426,674	306,000		
63	Lafourche Crossing, *Lafourche*	1939	120		235,725	200,000		
64	Lake Hermitage, *Plaquemines*	1934	100	0	150,000	9,200		
65	Lake Long, *Lafourche*	1937	2,500		1,293,293	503,197		
66	Lake Mongoulouis, *St. Martin*	1939	60		9,000	4,000		
67	Lake Pelto, *Terrebonne*	1929	100		1,898,570	516,000		
68	Lake Salvador, *St. Charles*	1940	100		40,000	40,000		
69	Lake Verrett, West, *St. Martin*	1938	400	400	307,234	171,322	646	469
70	Lake Washington, *Plaquemines*	1931	150	0	2,870,000	191,000		
71	La Pice, *St. James*	1939	160		43,812	40,210	2,450	2,242

TABLE I.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent
32					9		1	0					
33					15								
34	1	0	0	0	0	1[1]	1	0	*x*	*x*		51.9	*y*
35	3	1	0	1	0	2	2	0	*y*	*y*	0	56	*y*
36	89	48	0	0	89	0	86	3	3,808	3,190		44	0.04
37					1								
38					5								
39													
40					25								
41					17								
42					47								
43					153								
44					15								
45	14	8	0	0	14	0	14	0				32.7	
46	6	1	0	0	6	0	4	2				27	
47	11	1	2	0	6	0	6					42–47	
48	99	10	4	3	58	2	26	32	2,600	*y*		22–32–37	*y*
49	2	1	0	0	2		2	0	4,440	4,000		39	0.12
50					53								
51					3								
52					5								
53													
54	2	0	0	0	2		2	0	4,800	3,600		36	0.10
55	87	7	0	3	57	1	51	6	3,100	3,000		38	0.09
56					21								
57					7								
58	669	20	*y*	*y*	137	*y*	*y*	*y*			*y*	23–40	
59	6	3	0	0	0	6[1]	6	0	4,000; 4,100; 6,200	4,000–6,100		48–54	*y*
60					1								
61					50								
62					22								
63					4								
64	4	0	0	0	2	0	0	2				32.1	0.06
65	11	1	0	0	7	4	11	0	{4,220 5,060	4,220 5,060}		40	
66													
67					13								
68					3								
69	6	4		1 gas	5		5		*x*	3,600		37	0.10
70	13	0	0	0	7	0	7	0	*y*	*y*		18	0.73
71	3	2			1	2[1]	3		6,000	3,800		50 38 Dist. Oil	0.10

TABLE I.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
32	Miocene	Mio	Sand	Por	3,206	6,842	15	DS	Miocene	7,918
33	Miocene	Mio	Sand	Por	2,750	4,350	y	DS	Vicksburg	7,000
34	Linscomb sand	Olig	Sand	Por	8,950	8,988	38	MF	Cockfield	13,210
35	Cibicides	Olig	S	Por	7,300		20	MF	Vicksburg (Olig)	9,010
36	Cockfield and Wilcox	Eoc	S	Por 25	6,430 8,450	6,450 8,570	20,120	AF	Wilcox	8,813
37										11,991
38	Miocene	Mio	Sand	Por	3,150	8,000	7	DS	Miocene	12,125
39		Mio	Sand		5,512	5,595		DS	Miocene	10,725
40	Miocene	Mio	Sand	Por	4,072	6,993	15	DS	Miocene	7,200
41	Miocene	Mio	Sand	Por	8,880 9,460	8,887 9,518	40	D	Miocene	11,440
42	Miocene Oligocene	Mio-Olig	Sand	Por	5,156	7,050	50	AF	Vicksburg	9,246
43	Miocene	Mio	Sand	Por	8,500	8,510	10	D	Miocene	12,526
44	Miocene	Mio	Sand	Por	6,118	9,990	30	D	Miocene	10,453
45	Miocene	Mio	Sand		6,700	8,960	270	D	Miocene	9,796
46	Gueydan Capind Gueydan Flank	Mio	Sand	30²		9,250 3,500 4,300	40	DS	U Oligocene	9,975
47	Miocene	Mio	Sand	32	6,676	7,158	12	DS?	Lower Miocene	9,835
48	Amphistegina-Marginulina	Mio Olig	S	34	3,000 4,500 7,200 9,700	3,000–10,000	48–80–50–245	DS	Marginulina (Olig)	10,631
49	T. and W. sands	Olig	Sands	Por	19,746 29,949	19,768–29,968	122–219	DS	Olig	10,900
50		Mio Olig	Sand	30	3,100 3,900 4,300 5,900 7,200	8,210	45	SD	Oligocene	8,265
51		Olig	Sand	Por	9,745	9,770	25	DS	Frio	10,000
52	Miocene	Mio	Sand	Por	10,863 10,873		40	D	Miocene	12,777
53										
54	Peters	Mio	Sand	30	10,300	10,320	7	DS	Mio	11,344
55	1-1D 5-6-7 & Frio	Mio Olig	Sand	30	H6 sand 6,850	6,950	50	DS	Vicksburg	9,161
56		Mio	Sand					DS	Miocene	11,634
57	Miocene	Mio	Sand	Por	7,827 8,170	7,837 8,210	40	DS	Miocene	9,921
58	Upper Miocene to Marginulina	Mio Olig	Sand		1,883	8,230	120	DS	Vicksburg	10,766
59	8,600 ft., 8,800 ft., 9,500 ft.	Mio Olig	S	31.5	8,600 8,800 9,500	8,661 8,846 9,548	32–16–11	DS	Marginulina (Olig?)	10,953
60	Oligocene	Olig	Sand	Por	10,595	10,638	y	DS	y	11,469
61	Miocene	Mio	Sand	Por	8,035	10,130	80	D	Miocene	12,115
62	Miocene	Mio	Sand	Por	3,777	3,830	75	DS	Miocene	11,333
63		Mio			10,151	10,133	6	DS	Miocene	10,998
64	Miocene	Mio	Sand	25	3,150 4,550	3,166 4,595	15	DS	Miocene	9,786
65	Miocene	Mio	Sand	Por	9,360	10,430	9,360 10,432	AF	Miocene	11,347
66	Miocene	Mio	Sand	Por	9,952 1,274	9,970 1,373	18	DS	Miocene	10,788
67	Miocene	Mio	Sand	Por	1,274 6,248	1,373 6,270	55	DS	Miocene	7,270
68	Miocene (?)		Sand		9,775	9,800	(?)	D	Miocene (?)	10,500
69	L. sd; D. sd; N. sd; R. sd; U. sd; and V. sd.	Mio	Sand	30	N. Sd. Aug. 7,462	7,518	33	DS	Olig	11,678
70	Cap rock	Plio	Time Cap	23	1,125	1,150	25	DS	Miocene	6,445
71	V sd., 1 well; "Het," 2 wells	Mio Olig	Sand	25	10,950–7,604	11,000 7,655	40–17	DS	Heterostegina	11,402

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940
72	La Place, *St. John the Baptist*	1939		480	30,826[1]	26,653[1]	1,295,000	1,162,052
73	Leesville, *Lafourche*	1931	350		21,499,503	1,183,000		
74	Linette, *Terrebonne*	1937	0	600	63,000[1]	24,000[1]		
75	Little Cheniere, *Cameron*	1940	20		5,000	5,000		
76	Lockport, *Calcasieu*	1924	520	0	14,928,022	309,581		
77	Neale, *Beauregard*	1940	400	0	330,000	330,000	85	85
78	New Iberia, *Iberia*	1917	240		21,180,664	3,045,000		
79	Mermentau, West, *Jefferson Davis*	1940	20		6,000	6,000		
80	Niblett, *Jefferson Davis*	1940			5,389	5,389	Not available	Not available
81	Paradis, *St. Charles*	1939	300		368,000	350,000		
82	Perkins, *Calcasieu*	1939	0	40	0	0		
83	Pine Prairie, *Evangeline*							
84	Port Barre, *St. Landry*	1929	500		8,986,000	840,000		
85	Potash, *Plaquemines*	1937	100	0	387,000	260,000		
86	Quarantine Bay, *Plaquemines*	1937	800		2,755,088	1,590,000		
87	Raceland, *Lafourche*	1938	120	40	1,196,779	741,299		548
88	Richie, *Acadia*	1940	20		4,000	4,000		
89	Roanoke, *Jefferson Davis*	1934	750		8,677,700	617,700	7,430[2]	430[2]
90	Roanoke, South, *Jefferson Davis*	1937	2,360	2,360	682,500	377,700	9,142	6,092
91	Section 28, *St. Martin*	1940						
92	St. Martinsville, *St. Martin*	1935	100	0	1,119,484	124,942	399	45
93	Sorento, *Ascension*	1928	100	0	1,867,000	70,550		
94	Starks, *Calcasieu*	1925	100		3,081,513	160,000		
95	Stella, *Plaquemines*	1940	350*x*		20,955	20,955		
96	Sulphur Mines, *Calcasieu*	1926	320	0	14,957,636	985,898	0	0
97	Sweet Lake, *Cameron*	1926	190	10	4,749,540	534,381	*x*	*x*
98	Tepetate, *Acadia*	1935	1,200	1,200	9,583,817	1,571,371	44,569	8,915
99	Tepetate, North, *Acadia*	1938	0	1,000	95,278	28,195	3,000	1,000
100	Timbalier Bay, *Lafourche*	1938	40		160,000	70,000		
101	University, *S. Baton Rouge, E. Baton Rouge*	1938	530	425	2,893,000	1,792,000	1,500,000	700,000
102	Valentine, *Lafourche*	1936	160		4,586,000	865,000		
103	Venice, *Plaquemines*	1937			2,054,901	857,311	1,767	665
104	Vermilion Bay, *Iberia*	1939	50		127,000	80,000		
105	Ville Platte, *Evangeline*	1937	2,800	2,800	8,818,206	4,462,848	33,823	23,400
106	Vinton, *Calcasieu*	1910	270		45,332,300	310,000		
107	Welch, *Jefferson Davis*	1902	50	10	645,688	8,238	0	0
108	West Bay, *Plaquemines*	1940			4,000	4,000		
109	White Castle, *Iberville*	1929	200		4,261,866	795,850	2,684[2]	948[2]
110	White Lake, East, *Vermilion*	1940	50		12,000	12,000		
111	Woodlawn, *Jefferson Davis*	1938	360	700	1,555,736	873,233		

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil	
	Completed to End of 1940	During 1940		End of 1940			Number of Wells		Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
		Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift					
72	3	2	0	0	0	3	3	0	3,800 / 4,100	3,800 / 4,100		60°	
73					88								
74	7	0	0	1	0	6	7	0	y	y		48	0.34
75					1								
76	120	1	1	0	22	0	2	20					
77	10	10	0	0	10	0	10	0	3,700	3,000		37	y
78					84								
79					1								
80	1	1	1									42	0.2
81					7								
82	1	0	0	1	0	0			y	y			
83													
84					36								
85	9	5	0	0	9	0	9	0	y	y		28	0.10
86					17								
87	8	3	0	0	6	2	6		4,615	4,465		36	0.2
88					1								
89	35	0	5	0	17	1	14	3	x	3,250		38	
90	10	3			10[1]		10		x	6,508		53	0.10
91													
92	2	0	0	0	2	0	2	0	2,547 # est. @ 5,536	2,498 #-5,536			0
93	16	1	2	1	7	0	6	1				22–32	0.5
94					14								
95	2	2	0	0	2		2					(1)42–(2)35	0.2
96	129	8	9	25	57	0	8	49				18–32	
97	17	6	0	2	12	1	11	1	x	x		29	x
98	59		2	2	50	2	50		3,640	2,426	PM	36	–0.2
99	7	0	0	6	0	1	1	0	4,566	y		52	y
100					2								
101	43	11	1	2	40	2	41	1				33.2	
102	30	4	0	3	25		3	12	Variable—9 prod. sands			30–38	0.2
103	17	6	0	3	14	0	14	0	3,224–7,100	3,114		41	0
104					2								
105	148	64		2	146	2	148		4,070 (Tate)	2,597 (Tate)	PM	44	–0.1
106					57								
107	70	1	y	y	13	0		13	y	x		22	y
108													
109	22	6	0	2	14	1	12	3	x	2,600		26 oil 50 dist.	
110													
111	21	9	0	0	15	6	15	0	3,000 to 4,000	same		35	?

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
72		Mio	Soft Unconsolidated Sands	Por	8,100	8,900	12–30′	DS	Oligocene (?)	11,005
73	Miocene	Mio	Sand	Por	2,929	6,530	50	D	Miocene	9,723
74	Mio	Mio	Sand	30%	8,400 10,520	8,450– 10,524	50	D	Miocene	12,165
75	Mio, Het Marginulina	Mio Middle Olig	Sand	—	3,700	—			Hackberry	7,902
76	Het, Marginulina Miocene	Mio Mid Olig	Sands		3,700	6,483			Hackberry	7,902
77	Wilcox	Eoc	S	25	8,360	8,450	10	AF	Upper 260 of Wilcox	8,612
78	Pliocene-Miocene	Pli-Mio	Sands	Por	2,760	6,159	50	DS	Miocene	9,968
79										11,748
80	Marginulina	Olig	Sand	P	11,604	11,624	20	D	Marginulina Frio	11,748
81	Miocene	Mio	Sand	Por	10,187	10,212	60	DS	Miocene	11,555
82	Frio	Olig	Sand	30%	7,038	7,042	4	D	Cockfield	9,450
83										
84	Mio-Olig	Mio	Sand	Por		{ 3,190 4,950 }	25	DS	Frio	7,213
85	Mio	Mio	Sand	27%	{ 7,900– 8,350	8,000– 8,400 }	10–150	DS	Miocene	10,027
86	Miocene	Mio	Sand	Por	7,688	8,559	20	DS	Miocene	10,014
87		Mio	S	Por	10,135	10,210	75	DS	Salt	9,870
88										
89	5–6–7 sand	Olig	Sand	30	#6 sand 8,750	8,850	35	DS	Vicksburg	10,750
90	Heterostegina	Olig	Sand	Por	9,942	9,967	21	DS	Marginulina	12,088
91					1,250	2,500		DS		9,411
92	Miocene	Mio	Sands	30	5,500	5,572	20	DS	Vicksburg	9,646
93		Plio Mio	Soft sands	Por	900 4,378	900 4,378	20	SD	Oligocene	8,004
94	Cap rock Miocene	Mio	DL	Por	1,188	y	y	DS	Jackson	7,420
95		Mio	S		(1)7,510 (2)9,950		(1)15–(2)30	AF	Miocene	10,807
96		Mio Olig	Sand	±30%	2,800– 7,000			DS	Oligocene	7,500
97		Mio	Sand	Por	4,457	7,387	y	DS	Miocene	8,928
98	Ortego	Olig	Sand	P	8,300	8,338	38	D	Marginulina	9,447
99	Frio	Olig	S	25	{ 7,930 8,460 9,036 }	8,807	37	AF	Frio	9,487
100	Miocene	Mio	Sand	Por	5,320	{ 5,340 6,795 }	15	DS	Miocene	8,728
101		Mio	Uplift on Mio		4,100	7,200	27		Oligocene	10,360
102		Mio	Soft sand	Por	{ 3,800 9,300	3,800 9,300 }	535	DS	Miocene	11,001
103	Several individual sands	Mio	Sand	25% to 30%	3,600	10,700	30–125	DS	Buras sand	10,700
104	Miocene	Mio	Sand	Por	10,131	10,241	110	DS	Miocene	10,622
105	Sparta (Haas) Tate Wilcox	Eocene	Sand	P	9,020	9,080	60	D	Wilcox	10,939
106	Miocene	Mio	Sand	Por				DS	Vicksburg	6,939
107	None	Pli-Mio	S	y	1,300–5,300	y	10–15	DS	Hackberry (Olig?)	10,358
108										
109	Wilbert 4–8–9–Dis	Mio Olig	Sand	Por	6,330	6,385	50	DS	Discorbis	8,777
110										
111		Marginulina Olig	Sand	27%	8,000–9,500		Various	Domal Graber	Hackberry in basal Marg	10,194

oil sand at 7267 ft. and made an unusually good producer of 32° gravity oil on completion. The East White Lake discovery of the Union Oil of California is undoubtedly of major importance. This field is near the east edge of White Lake in Vermilion Parish. Oil was found in sand at a depth of 10,536 feet.

The amount of proven oil reserves in newly discovered fields is conservatively estimated at 75,000,000 bbl. This figure will be rapidly lifted with increasing field developments. Reserves in new sands in old fields have not been estimated but are considered to be large. The discoveries of 1940 in southern Louisiana pave the way for an extensive drilling program in 1941.

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Oil and Gas Development in Michigan during 1940

By Theron Wasson,* Member A.I.M.E.

No major oil-field discoveries were made in Michigan during the year 1940. Production for the year was maintained by discoveries made in 1938 and, as a result, is below the total for 1939. Several extensions to old fields have been made, which have helped to maintain production in the face of rather rapid decline in the fields of the southwestern part of the state. Important extensions were made in Overisel, Porter, Sherman, and Adams fields. Important oil and gas fields of the state are shown on the map, Fig. 1.

Michigan's production of 19,700,000 bbl. during 1940 was 3,800,000 bbl. less than the total for 1939, but about one million greater than 1938. This brings the total accumulated production for the state to a little over 145,000,000 bbl.

Active Oil Fields

The leading producer for the year was the Temple field, Clare County, where 29 new wells were drilled. The Walker field, Kent County, was second, but drilled 183 new wells in order to gain that position. In the extension of the Overisel field in Allegan County, 115 new producers were drilled. The Adams field, Arenac County, was revived by several wells with initial productions of over 1000 bbl. per day from the Dundee of Devonian age.

Active Gas Fields

Two important gas fields were discovered by Taggart Brothers during the year. The first was in Riverside township, Missaukee County; the second in Marion township, Osceola County. Both are producing from the Stray sand at about 1350 ft. These fields are on structures found by core testing through the glacial drift. The Six Lakes field, Montcalm County, discovered in 1934, is Michigan's largest gas-producing field. It has 195 wells producing from the Michigan Stray sandstone and the Upper Marshall sandstone. This field was developed on a 40-acre spacing plan.

Wildcat Drilling

A test in sec. 29, Winterfield township, Clare County, which is producing oil from the Monroe of Devonian age at a depth of 3760 ft., and a well in sec. 31, Lincoln township, Osceola County, producing from the Monroe at 3625 ft., should be classed as wildcats that are sure to lead to further development in 1941.

At the end of the year the Gulf Refining Company's deep test on the Kawkawlin structure in Monitor township, Bay County, was preparing to drill deeper after having had a gas blowout from a depth of 7775 ft. This test is the most important one drilling at the end of the year in Michigan, for should it develop commercial production from deeper beds it will lead to deeper drilling on many well-known structures that have been producing from shallower sands.

Exploration

A small amount of reflection seismograph work was done in Clare, Osceola, and Gladwin Counties during the year. Exploration by shallow drilling for structural information on beds below the glacial drift con-

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FIG. 1.—OIL AND GAS FIELDS OF MICHIGAN IN 1940.

TABLE 1.—*Oil and Gas Production in Michigan*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells					
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
1	Adams, *Arenac*	1937	800	0	433,574	313,199	0	0	28	13	4	0	22	0
2	Austin (Gas), *Mecosta*	1935	0	2,200	0	0	5,660	421	29	0	3	0	0	14
3	Bangor, *Van Buren*	1939	240	0	174,811	97,139	0	0	16	6	4	0	12	0
4	Beaverton, *Gladwin*	1935	600	0	599,444	34,916	0	0	28	0	2	0	14	0
5	Bentley, *Gladwin*	1937	1,000	0	537,431	124,701	0	0	38	1	2	0	35	0
6	Birch Run, *Saginaw*	1934	300	0	180,807	10,092	0	0	28	0	0	0	25	0
7	Bloomingdale, *Van Buren*	1938	1,200	0	4,864,549	979,737	0	0	160	7	18	0	106	0
8	Broomfield (Gas), *Isabella*	1930	0	4,100	0	0	6,343	404	54	0	1	0	0	35
9	Buckeye, North, *Gladwin*	1936	2,900	0	13,771,349	822,404	0	0	262	0	26	0	204	0
10	Buckeye, South, *Gladwin*	1936	2,500	0	3,560,328	183,049	0	0	188	1	46	0	94	0
11	Clare (Gas), *Clare*	1929	0	400	0	0	697	46	9	0	2	0	0	6
12	Clare City, *Clare*	1938	20	640	11,048	3,637	842	473	7	1	1	0	2	7
13	Clayton, *Arenac*	1936	1,300	560	3,214,631	417,144	1,593	1,269	88	7	2	0	51	28
14	Columbia, *Van Buren*	1938	1,100	0	1,714,058	499,720	0	0	101	10	28	0	65	0
15	Crystal, *Montcalm*	1935	2,180	200	7,075,813	83,053	338	23	240	0	3	0	25	5
16	Deerfield, *Monroe-Lenawee*	1935	240	0	152,712	109,102	0	0	28	17	2	0	26	0
17	Diamond Springs, *Allegan*	1938	560	0	653,265	77,395	0	0	55	0	5	0	27	0
18	Dorr, *Allegan*	1938	360	0	240,761	30,842	0	0	24	0	3	0	18	0
19	Edmore, *Montcalm*	1933	160	0	404,325	18,466	24	24	13	0	0	0	6	0
20	Edenville, *Midland*	1938	400	0	1,029,266	109,836	0	0	35	0	5	0	26	0
21	Freeman (Gas), *Clare*	1938	0	1,760	0	0	373	288	14	1	2	0	0	13
22	Gratiot, *Gratiot*	1927	0	400	228	0	4	0	3	0	0	0	0	0
23	Hart, *Oceana*	1932	160	0	116,275	0	0	0	17	0	0	0	0	0
24	Home (Gas), *Montcalm*	1938	0	5,000	0	0	1,332	733	24	9	1	0	0	23
25	Lake Mill, *Van Buren*	1938	500	0	284,059	52,782	0	0	29	5	5	0	17	0
26	Leaton, *Isabella*	1929	2,100	480	2,750,465	136,710	186	9	90	0	5	2	44	0
27	Lincoln (Gas), *Clare*	1938	0	2,720	0	0	510	444	14	6	0	0	0	14
28	Marion (Gas), *Osceola-Clare*	1940	0	5,600	0	0	0	0	12	12	0	12	0	0
29	Monterey, *Allegan*	1938	300	0	322,889	44,729	0	0	28	3	3	0	19	0
30	Mt. Pleasant, *Midland-Isabella*	1928	8,000	0	21,140,777	412,696	4,820	347	442	1	8	0	190	0
31	Muskegon, *Muskegon*	1927	2,700	0	6,656,162	38,391	7,758	37	412	1	27	8	47	0
32	New Haven (Gas), *Gratiot*	1935	0	2,400	0	0	2,571	677	51	0	0	0	0	48
33	Overisel, *Allegan*	1938	2,070	0	1,475,365	1,028,271	0	0	153	115	12	0	131	0
34	Porter-Yost, *Midland*	1931	8,440	0	36,648,826	1,744,589	2,301	323	531	13	27	0	335	0
35	Ravenna (Gas), *Muskegon*	1936	0	3,840	0	0	1,107	38	29	0	1	27	0	0
36	Riverside (Gas), *Missaukee*	1940	0	3,000	0	0	0	0	4	4	0	0	0	0
37	Saginaw, *Saginaw*	1925	1,800	0	1,349,552	22,164	0	0	282	0	0	0	55	0
38	Salem, *Allegan*	1937	2,350	0	2,491,695	404,087	20	14	177	18	21	0	143	0
39	Salem New, *Allegan*	1938	1,130	0	2,362,519	1,045,889	0	0	102	11	3	0	94	0
40	Sherman, *Isabella*	1936	1,220	0	3,609,733	459,752	0	0	95	8	1	0	62	0
41	Six Lakes (Gas), *Mecosta-Montcalm*	1934	0	10,120	0	0	21,825	5,353	244	2	10	0	0	195
42	Temple, *Clare*	1938	2,710	0	10,207,223	4,432,779	946	946	163	29	13	0	140	0
43	Tallmadge, South, *Kent*	1939	560	0	36,462	34,478	0	0	25	21	2	0	20	0
44	Vernon, *Isabella*	1930	1,100	880	4,135,400	154,023	1,361	40	91	0	5	0	34	6
45	Walker, *Kent*	1938	5,500	0	7,030,013	4,208,933	1,709	1,709	469	183	11	1	457	0
46	West Branch, *Ogemaw*	1933	5,000	0	4,148,713	490,717	0	0	257	6	6	0	235	0
47	Winfield (Gas), *Montcalm*	1938	0	1,920	0	0	789	355	14	3	0	0	0	14
48	Wise, *Isabella*	1938	1,200	0	1,125,906	848,261	49	3	65	46	1	0	62	4
49	Wyoming Park, *Kent*	1939	450	0	66,047	53,321	0	0	21	11	0	0	15	0
50	Miscellaneous				655,305	202,118	5	4	75	9	16	3	62	7
51	Total		65,000	46,220	145,231,786	19,728,167	63,163	13,980	5,364	580	337	57	2,920	419

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE 1.—(*Continued*)

Line Number	Oil-Production Methods, End of 1940: Number of Wells		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
	Flowing	Artificial Lift	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	0	22	y	y	0	37.0 34.3	y y	Traverse Dundee	Dev	L	P	2,031 2,841	2,039 2,921	15 16	A	Dundee	3,111
2	0	0	512	y	0	0	y	Stray-Marshall	Mis	S	P	1,390	1,410	10	A	Monroe	4,042
3	0	12	y	y	0	28.5	y	Traverse	Dev	L	P	1,002	1,006	2	A	Traverse	1,050
4	0	14	y	y	0	41.3	0.16	Dundee	Dev	L	P	3,880	3,895	12	A	Dundee	4,025
5	0	35	y	y	0	41.4	y	Dundee	Dev	L	P	3,500	3,536	25	A	Dundee	3,685
6	0	25	y	y	0	42.4	0.25	Berea	Mis	S	P	1,529	1,546	13	A	Dundee	2,760
7	0	106	y	y	0	41.2	0.79	Traverse	Dev	L	P	1,216	1,219	2.5	A	Monroe	1,904
8	0	0	580	y	0	0	y	Stray-Marshall	Mis	S	P	1,300	1,350	5	A	Monroe	3,788
9	0	204	y	y	0	39.0	0.25	Dundee	Dev	L	P	3,621	3,647	11	A	Monroe	4,696
10	0	94	y	y	0	39.0	0.25	Dundee	Dev	L	P	3,574	3,597	11	A	Monroe	4,330
11	0	0	605	y	0	0	y	Stray-Marshall	Mis	S	P	1,408	1,413	5	A	Monroe	4,055
12	0	2	605	y	0	y	y	Stray-Marshall	Mis	S	P	1,283	1,293	65	A	Monroe	3,865
13	0	51	620	y	0	34.3	y	Berea (gas) Dundee (oil)	Mis Dev	S L	P	1,166 2,534	1,189 2,576	12 12	A	Dundee	2,707
14	0	65	y	y	0	y	y	Traverse	Dev	L	P	1,190	1,193	2.5	A	Monroe	1,904
15	0	25	448	y	0	41.3	0.37	Stray-Marshall (gas) Monroe (oil)	Mis Dev	S D	P	1,016 3,191	1,021 3,202	4 4	A	Monroe	3,520
16	0	26	y	y	0	40.0	y	Trenton	Ord	L	P	2,102	2,114	9	MF	St. Peter	2,512
17	0	27	y	y	0	y	y	Traverse	Dev	L	P	1,466	1,472	3.5	A	Traverse	1,571
18	0	18	y	y	0	41.4	0.44	Traverse	Dev	L	P	1,596	1,507	4	A	Monroe	2,065
19	0	6	900	y	0	43.2	0.11	Traverse	Dev	L	P	3,108	3,112	4	A	Monroe	3,700
20	0	26	y	y	0	41.3	y	Dundee	Dev	L	P	3,788	3,796	8	A	Dundee	4,015
21	0	0	607	y	0	0	y	Stray-Marshall	Mis	S	P	1,486	1,512	12	A	Monroe	3,956
22	0	0	y	y	0	y	y	Parma	Pen	S	P	500	510	10	MC	Dundee	3,100
23	0	0	x	0	0	34.0	y	Traverse	Dev	L	P	1,880	1,890	4	A	Dundee	2,407
24	0	0	515	y	0	0	y	Stray-Marshall	Mis	S	P	1,390	1,400	7.5	A	Monroe	3,665
25	0	17	y	y	0	y	y	Traverse	Dev	L	P	1,277	1,279	1.5	A	Monroe	1,820
26	0	44	550	y	y	43.0	0.16	Stray-Marshall (gas) Dundee (oil)	Mis Dev	S L	P P	1,239 3,634	1,243 3,681	4 7.5	A	Monroe	4,390
27	0	0	607	y	0	0	y	Stray-Marshall	Mis	S	P	1,526	1,538	10	A	Monroe	4,285
28	0	0	y	y	0	0	y	Stray-Marshall	Mis	S	P	1,392	1,408	9	A	Monroe	3,945
29	0	19	y	y	0	y	y	Traverse	Dev	L	P	1,638	1,647	3	A	Traverse	1,808
30	0	190	y	y	y	41.5	0.13	Dundee	Dev	L	P	3,536	3,568	14.6	A	Sylvania	4,821
31	0	47	y	y	0	37.4	0.56	Traverse-Dundee	Dev	L	P	2,050	2,075	10	A	St. Peter	4,754
32	0	0	448	y	0	0	y	Stray-Marshall	Mis	S	P	915	950	5	A	Dundee	3,657
33	0	131	y	y	0	41.7	y	Traverse	Dev	L	P	1,471	1,481	3	A	Traverse	1,690
34	1	334	y	y	y	41.3	0.26	Dundee	Dev	L	P	3,422	3,434	12	A	Sylvania	4,733
35	0	0	720	y	0	0	y	Berea	Mis	S-D	P	1,212	1,233	10	y	Dundee	2,306
36	0	0	y	y	0	y	y	Stray-Marshall	Mis	S	P	1,331	1,355	15.7	A	Monroe	3,912
37	0	55	y	y	0	44.3	0.24	Berea	Mis	S	P	1,820	1,850	16	A	Sylvania	3,970
38	0	143	y	y	0	41.5	y	Traverse	Dev	L	P	1,587	1,601	8	A	Dundee	1,950
39	0	94	y	y	0	41.0	y	Traverse	Dev	L	P	1,621	1,631	6	A	Monroe	1,968
40	0	62	y	y	0	47.8	y	Monroe	Dev	D	P	3,648	3,652	4	A	Monroe	4,031
41	0	0	516	y	0	0	y	Stray-Marshall	Mis	S	P	1,275	1,300	16	A	Monroe	3,529
42	15	125	y	y	0	43.8	0.37	Monroe	Dev	D	P	3,895	3,900	4.5	A	Monroe	3,954
43	0	20	y	y	0	42.0	y	Traverse	Dev	L	P	1,820	1,845	7.5	A	Traverse	1,936
44	0	34	575	x	y	44.1	0.30	Monroe	Dev	D	P	3,741	3,743	3.0	A	Monroe	3,907
45	0	457	y	y	0	41.0	y	Traverse	Dev	L	P	1,827	1,848	6.0	A	Monroe	2,400
46	0	235	y	y	0	33.4	0.35	Traverse Dundee	Dev	L	P	1,880 2,622	1,910 2,707	5 20	A	Monroe	3,637
47	0	0	446	y	0	0	y	Stray-Marshall	Mis	S	P	1,124	1,141	8	A	Monroe	3,374
48	0	62	y	y	0	43.0	y	Dundee	Dev	L	P	3,702	3,716	10.5	A	Dundee	3,723
49	0	15	y	y	0	y	y	Traverse	Dev	L	P	1,191	1,218	6	A	Traverse	2,102
50	0	62															
51	16	2,904															

tinued on a larger scale than in previous years.

Proration

Early in the year most of the active fields had an allowable of 100 bbl. per day; this was revised by an order effective March 15, which prorated fields as follows: New Salem, Walker-Wyoming-Tallmadge and Overisel, each 100 bbl. per well per day; Temple, 10-acre spacing, 75 bbl. per well per day; 20-acre spacing 150 bbl. per well per day. Effective Oct. 1, 1940, proration was lifted from all fields, with the exception of the wells in Redding township, Clare County, spaced at 20 acres, which remained at 150 bbl. per well per day.

Prices

At the end of the year crude-oil prices were 15¢ to 20¢ per barrel higher than at the beginning of the year.

Acknowledgments

Mr. Carl C. Addison, Division Geologist of The Pure Oil Co. at Saginaw, Mich., and Mr. D. C. Shackleford, Chief Scout of that company, assisted in the preparation of this report. The State Geological Survey of Michigan furnished production data on oil and gas.

Table 2.—*Summary of Drilling Operations in Michigan*

Important Wildcats Drilled in 1940
Surface Formation, Pleistocene

	County	Location Sec.	Twp.	Rge.	Total Depth, Ft.	Deepest Horizon Tested	Drilled by	Initial Production per Day Oil, U. S. Bbl.	Gas, Millions Cu. Ft.	Remarks
1	Allegan..	8	4 N	14 W	1,479	Traverse	H. C. Nelson	150		Discovery causing northern extension Overisel
2	Arenac..	22	19 N	3 E	2,879	Dundee	Don Rayburn	1,981		Discovery causing northern extension Adams
3	Barry...	8	3 N	9 W	5,013	St. Peter	Sun Oil Co.			First St. Peter test in Barry County. Good show oil in St. Peter
4	Bay.....	2	14 N	4 E	?	Salina	Gulf Refining Co.	Testing	Testing	Important deep test, 12,000,000 cu. ft. gas in Salina. Preparing to drill deeper
5	Clare....	15	19 N	3 W	3,753	Dundee	Sun Oil Co.	1,512		Produced 10,344 bbl. before abandonment and caused additional prospecting
6	Clare....	35	20 N	6 W	3,797	Dundee	Sun Oil Co.	50		Discovery well sec. 35, Winterfield township
7	Clare....	29	20 N	6 W	3,772	Dundee	Rowmor Corp. & Hughes	359		Discovery well sec. 29, Winterfield township
8	Gladwin.	10	18 N	2 W	3,841	Dundee	Sun Oil Co.	15		Discovery well Grout township
9	Huron...	8	17 N	14 E	3,422	Monroe	Wallace & Markle	26		First discovery of oil in Monroe formation in Bloomfield township
10	Osceola..	31	18 N	10 W	3,635	Monroe	Weber Oil Co.	29		Discovery of oil in Monroe formation, Lincoln township

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	68	89
Number of oil wells completed during 1940	527	20
Number of gas wells completed during 1940	53	7
Number of dry holes completed during 1940	185	370

Oil and Gas Development in Mississippi during 1940

By H. M. Morse*

During the year of 1940, wildcat wells were drilled in 32 counties of Mississippi; 85 wells in all. These were scattered over the state from the most northern county to the southern counties and from the Mississippi River on the west to the Alabama line on the east. Yazoo County, with 19, received the largest number.

The average depth of all the wells was 5333 ft. The shallowest well completed as a dry hole was in Yalobusha County, abandoned at 1392 ft. in the Selma. The deepest well drilled was in Scott County, abandoned at 10,365 ft. in the Lower Cretaceous Paluxy. G. C. Grasty drilled the Kentucky Lumber Company No. 1 well, sec. 7, T. 10 S., R. 10 E., Itawamba County, to a depth of 3530 ft. and bottomed his hole in the Ordivician.

Tinsley Oil Field.—In the Tinsley oil field 104 wells were completed as producers during 1940. Five producing sands have been logged with a total average thickness of 157 ft. of oil sand. One of these sands is in the Selma, three in the Eutaw, and one in the Tuscaloosa.

Vaughan-Pickens Field.—The Vaughan-

Manuscript received at the office of the Institute March 27, 1941.

* State Oil and Gas Supervisor, Jackson, Mississippi.

Table 1.—*Oil and Gas Production in Mississippi*

Line Number	Field	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
1	Jackson gas field........	1930	0	7,600	0	0	106,497,619,000	6,448,737,000	146	1	7	0	0	27
2	Tinsley oil field..........	1939	5,880	0	4,324,192	4,209,223	0	0	112	104	0	0	112	0
3	Vaughan-Pickens oil field	1940	40	0	286,256	286,256	0	0	4	4	0	0	4	0

Line Number	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1			980	880				Selma	CreU	C	x	2,420	2,435	15	A	Trinity	5,529
2	37	75	250	125	0	37.3	0.748		CreU	sand	x				AF	Tuscaloosa	6,430
3	0	4	0	0	0	38.4	x	Wilburn (Eutaw)	CreU	sand	x	4,880	4,890	6	F	Tuscaloosa	6,031

[b] Footnotes to column heads and explanation of symbols are given on page 256.

Pickens oil field was discovered by the Exchange and Kingwood Oil Companies in sec. 31, T. 12 N., R. 3 E., Yazoo County; the Wilburn No. 1 well was put to producing on April 8, 1940. The producing sand is in the Eutaw.

Exploration.—At one time during the early part of 1940, 75 geophysical crews were in operation, and the average was 40 for the year. Three salt domes were drilled and penetrated, two in Warren County and one in Lamar County.

Prospects.—Mississippi is not expecting more than 50 wildcat wells during 1941, but it is believed that those 50 will be more carefully drilled and located with regard to structural conditions than wildcat wells hitherto drilled.

TABLE 2.—*Summary of Drilling Operations in Mississippi*

Wildcats Drilled in 1940

	County	Company	Farm and Number	Location	Total Depth, Ft.	Bottom-hole Formation
1	Attala	Gulf Refining Co.	Peeler No. 1	NE SE sec. 35, T15 N, R 9 E	5,027	Lower Cretaceous
2	Attala	Hawkins & Matthews	Weeks No. 1	NW NW SW sec. 29, T15 N, R 6 E	5,017	Tuscaloosa
3	Attala	F. R. Jackson	Crosby No. 1	W½ NW NE sec. 3, T14 N, R 7 E	5,262	Tuscaloosa
4	Attala	F. R. Jackson	Federal Land Bank No. 1	NW SE sec. 29, T16 N, R 9 E	4,512	Lower Cretaceous
5	Clarke	Ark-Miss. Oil Co.	Long Bell No. 1	SW NE sec. 35, T 3 N, R17 E	7,011	Marine Tuscaloosa
6	Clarke	Ark-Miss. Oil Co.	School Land No. 1	SE NW sec. 16, T 2 N, R16 E	5,012	Tuscaloosa
7	Copiah	G. C. Koch	Broome No. 1	SW SE sec. 1, T 9 N, R 8 E	3,628	Tallahatta
8	Copiah	J. S. Wheless, Jr.	Columbian No. 1	NE NE sec. 19, T 1 N, R 3 W	8,005	Selma
9	Hinds	Royal Oil & Gas Co.	Hinds Jr. College No. 1	SW NE sec. 35, T 5 N, R 2 W	7,647	Eutaw
10	Holmes	Exchange Oil Co.	Gwin No. 1	NE NW SE sec. 6, T16 N, R 1 E	5,099	Tuscaloosa
11	Holmes	Exchange Oil Co.	Russell No. 1	NE NE SE sec. 32, T15 N, R 2 E	5,490	Eutaw
12	Holmes	Exchange Oil Co.	Thurmond No. 1	NW NW SE sec. 21, T15 N, R 3 E	5,003	Tuscaloosa
13	Holmes	Hawkins & Howell	Jones No. 1	NW NW sec. 27, T15 N, R 1 E	5,010	Eutaw
14	Holmes	Hawkins & Matthews	Ellis No. 1	NE SW sec. 18, T14 N, R 4 E	5,007	Tuscaloosa
15	Holmes	L. A. Hawkins	Humphreys No. 1	E½ SE NE sec. 33, T13 N, R 2 E	4,987	Selma
16	Holmes	Rowan Drilling Co.	Smith No. 1	NW NE sec. 7, T14 N, R 1 W	5,827	Tuscaloosa
17	Holmes	A. H. Rowan	Eakin No. 1	NW SE sec. 20, T14 N, R 1 E	6,007	Eutaw
18	Humphreys	Fohs Oil Company	Holladay No. 1	SW SW sec. 5, T13 N, R 3 W	5,200	Igneous
19	Humphreys	J. B. Moncrief et al.	State of Miss. No. 1	NW NW NE sec. 9, T15 N, R 2 W	5,522	Igneous material
20	Humphreys	Reid-Clark	Allen No. 1	NE SW SW sec. 4, T13 N, R 4 W	5,057	Igneous
21	Issaquena	Germany et al.	Mohanna No. 1	SE SW sec. 9, T18 N, R 3 E	6,023	Tuscaloosa ?
22	Issaquena	W. E. Hall et al.	Charping No. 1	NE NW sec. 29, T10 N, R 8 W	5,020	Paluxy ?
23	Itawamba	G. C. Grasty	Kentucky Lbr. Co. No. 1	N½ SE sec. 7, T10 S, R10 E	3,530	Ordovician
24	Jefferson Davis	Fred Courson	Bailey No. 1	SW SW NE sec. 4, T 6 N, R18 W	6,013	Wilcox
25	Jefferson Davis	Exchange Oil Co.	Newman Lbr. Co. No. 1	SE SE NE sec. 36, T 7 N, R19 W	5,025	Wilcox
26	Jefferson Davis	J. W. Richardson	Berry No. 1	SW NE sec. 15, T 9 N, R19 W	8,523	Tuscaloosa
27	Jones	R. W. Williams	Smith County Oil Co. No. 1	E½ NW sec. 1, T 8 N, R12 W	7,004	Selma
28	Kemper	A. E. Manning	Caldwell No. 1	SW SW sec. 25, T 9 N, R15 E	1,507	Selma
29	Kemper	A. E. Manning	Caldwell No. 1	SW SW sec. 25, T 9 N, R15 E	3,309	Tuscaloosa
30	Lamar	Miss. La. Oil Syndicate	Simmons No. 1	E½ NE NW sec. 32, T 3 N, R14 W	2,001	?
31	Lamar	Tatum Lbr. Co.	W. S. F. Tatum No. 1	NE sec. 14, T 2 N, R16 W	2,000	Salt
32	Leflore	Exchange Oil Co.	Wildwood No. 1	SE SE NE sec. 6, T20 N, R 1 E	5,329	Igneous
33	Madison	Ralph A. Johnston	Dinkins-Ray-Reid No. 1	SW SW sec. 14, T10 N, R 3 E	5,315	Eutaw
34	Madison	Ralph A. Johnston	Ray No. 1	SE SW sec. 6, T 8 N, R 3 E	7,409	Tuscaloosa
35	Madison	Ralph A. Johnston	School Land No. 1	NW NE NE sec. 16, T11 N, R 3 E	5,010	Eutaw
36	Madison	Ralph A. Johnston	Young No. 1	SE NE sec. 32, T11 N, R 4 E	5,078	Eutaw
37	Madison	Love Petroleum Co.	Parkinson No. 1	NW NE sec. 23, T 9 N, R 1 W	5,327	Eutaw
38	Madison	W. G. Ray	Haffey No. 1	S½ NW sec. 7, T10 N, R 5 E	5,046	Eutaw
39	Madison	Stanolind Oil & Gas	Higgason No. 1	SW SW sec. 10, T11 N, R 5 E	5,020	Tuscaloosa
40	Monroe	Willmut Gas & Oil Co.	Rye No. 1	SW NE NE sec. 22, T15 S, R17 W	2,745	Pennsylvanian
41	Montgomery	Gulf Refining Co.	Parker No. 1	SW SW sec. 22, T19 N, R 7 E	5,303	Pennsylvanian
42	Neshoba	J. P. Evans	Oliver No. 1	SW sec. 18, T 9 N, R13 E	4,018	Tuscaloosa
43	Newton	Kingwood Oil Co.	State of Miss. No. 1	NE NE SE sec. 27, T 8 N, R10 E	4,772	Tuscaloosa
44	Oktibbeha	N. W. Shiarella	Murphy No. 1	N½ NE NW sec. 28, T17 N, R12 E	4,025	Lower Cretaceous

TABLE 2.—(*Continued*)

Wildcats Drilled in 1940

	County	Company	Farm and Number	Location	Total Depth, Ft.	Bottom-hole Formation
45	Perry	Fohs Oil Co.	Bond Lbr. Co. No. 1	N½ SE NW sec. 17, T 1 S, R11 W	7,800	Tuscaloosa
46	Pike	S. R. Crouch	Cupit No. 1	SE SW sec. 25, T 2 N, R 7 E	2,430	?
47	Scott	Exchange Oil Co.	Newell Minerals No. 1	NW NE SW sec. 30, T 7 N, R 7 E	6,512	Tuscaloosa
48	Scott	Gulf Refining Co.	Newell Minerals No. 1	N½ NE NE sec. 5, T 6 N, R 7 E	10,365	Paluxy
49	Scott	E. L. Martin	Adams No. 1	S½ SW SE sec. 25, T 8 N, R 6 E	6,526	Tuscaloosa
50	Sharkey	Charles Crader	Wells No. 1	SW NW sec. 27, T12 N, R 7 W	4,015	Igneous
51	Sharkey	Eureka Petroleum Co.	Cooper No. 1	SE NE sec. 15, T14 N, R 6 W	3,742	Quartzite (Tuscaloosa)
52	Sharkey	Ralph Fair	Houston Estate No. 1	NE NE sec. 12, T10 N, R 7 W	4,060	Tuscaloosa
53	Simpson	Cleve Love	Garner No. 1	SW NE sec. 1, T10 N, R17 W	6,038	Midway
54	Smith	Haynes B. Ownby Drill Co.	School Land No. 1	SW NE NE sec. 16, T 2 N, R 9 E	6,512	Tuscaloosa
55	Stone	Harry I. Morgan	Dantzler Lbr. Co. No. 1	NW SE sec. 8, T 4 S, R12 W	8,771	Eutaw
56	Tallahatchie	Gulf Refining Co.	Cason No. 1	NE sec. 2, T21 N, R 1 W	5,909	Igneous
57	Tallahatchie	I. P. LaRue	Westbrook No. 1	SE SE SE sec. 18, T23 N, R 2 W	4,296	Tuscaloosa
58	Tallahatchie	Marshall R. Young	Ogilvie No. 1	SE NW sec. 32, T25 N, R 2 E	3,976	Igneous
59	Warren	W. O. Allen	Culley No. 1	SE NW sec. 6, T14 N, R 3 E	4,490	Salt
60	Warren	W. O. Allen	Tom Henry No. 1	W½ SW sec. 4, T 7 N, R 4 W	7,277	Eutaw
61	Warren	Magnolia Petroleum Co.	Brown-Paxton No. 1	SW SW SW sec. 12, T14 N, R 4 E	5,401	Salt
62	Warren	Burden-Cummings	Morrissey No. 1	NE sec. 8, T 17 N, R 2 E	6,001	Tuscaloosa
63	Wayne	Hill & Hill	Kalmia Realty No. 1	SW NE sec. 5, T 7 N, R 9 W	6,734	Eutaw
64	Yalobusha	Stewart & Hawkins	McRae No. 1	NE NE SW sec. 25, T24 N, R 6 E	2,957	Pennsylvanian
65	Yalobusha	J. E. Green	Goldman No. 1	SW SE NW sec. 23, T25 N, R 6 E	1,392	Selma
66	Yalobusha	Stewart Oil Co.	Creekmore No. 1	SW NE sec. 21, T24 N, R 7 E	3,724	Pennsylvanian
67	Yazoo	Arcarea Reserve	Holmes No. 1	SE SE sec. 22, T12 N, R 1 E	5,609	Eutaw
68	Yazoo	Conroe-Wilcox Minerals	Stubblefield No. 1	SW SW NW sec. 25, T12 N, R 1 W	5,655	Selma
69	Yazoo	Joe M. Dawson	McGraw Curran No. 1	NW NW sec. 19, T11 N, R 3 W	6,009	Eutaw
70	Yazoo	E. M. DeLoach	Wilburn No. 1	NW NW NW sec. 6, T12 N, R 1 W	6,019	Eutaw
71	Yazoo	Leon Dunn	Pepper No. 2	SE NW NW sec. 26, T12 N, R 2 E	4,943	Selma
72	Yazoo	Exchange Oil Co.	Bennett No. 1	NE NE SE sec. 28, T12 N, R 2 E	5,830	Tuscaloosa
73	Yazoo	Exchange Oil Co.	Edgar No. 1	SW NW NW sec. 28, T13 N, R 1 W	6,505	Tuscaloosa
74	Yazoo	Exchange-Kingwood	Wilburn* No. 1	NE NE NE sec. 31, T12 N, R 3 E	4,891	Eutaw
75	Yazoo	Hill & Hill	Kinkead Plantation No. 1	SE NW NE sec. 31, T11 N, R 3 W	5,328	Selma
76	Yazoo	Hill & Hill	Montgomery No. 1	SE SW SE sec. 23, T12 N, R 3 E	5,700	Tuscaloosa
77	Yazoo	Kingwood-Exchange	Shipp No. 1	E½ SW sec. 4, T10 N, R 1 E	6,067	Eutaw
78	Yazoo	Robert P. Lake	Exum Estate No. 1	NW NE sec. 13, T10 N, R 2 E	5,328	Eutaw
79	Yazoo	Nelson Brothers	Stoner No. 1	SE NW sec. 2, T11 N, R 5 W	5,013	Tuscaloosa
80	Yazoo	Petroleum Exploration	Vandevere No. 1	SW SW SE sec. 25, T13 N, R 1 W	6,345	Tuscaloosa
81	Yazoo	Sells Petroleum Co.	Falkner No. 1	SE NE sec. 34, T 9 N, R 4 W	6,500	Selma
82	Yazoo	Thompson, Rowan & Hope	Eliott & Edwards No. 1	SW NW NE sec. 30, T10 N, R 3 W	6,226	Eutaw
83	Yazoo	Whigate Oil Co.	Robertson No. 1	NW NW NW sec. 20, T10 N, R 2 W	5,008	Selma
84	Yazoo	Whigate & Sanford	Robertson No. 1	SW NW SE sec. 20, T10 N, R 2 W	5,307	Selma
85	Yazoo	Yazoo Realty (J. R. Lockhart)	Brooke No. 1	NE NW SE sec. 17, T10 N, R 2 W	5,236	Selma

Core holes completed in 1940: 6.

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940		
Number of oil wells completed during 1940	107	1
Number of gas wells completed during 1940	1	none
Number of dry holes completed during 1940	2 (gas)	84

* Discovery well of Vaughan-Pickens Oil Field.

Development of Oil and Gas in Missouri in 1940

By Frank C. Greene*

(New York Meeting, February 1941)

The wildcatting in northern and northwestern Missouri, which started in 1939, was continued in 1940. Two new gas fields were found and one discovered in 1939 was further extended. The total number of completions was 94, of which 5 were oil wells with about 48 bbl. initial production, 30 were gas wells with an initial open-flow capacity of 37,655,000 cu. ft., and 59 were dry holes.

The outstanding discovery was the Polo gas field, T. 55 N., R. 28 and 29 W., in Caldwell County. A sand now believed to be a lens in the Bandera shale at a depth of 400 ft. yielded flows of more than 12,000,000 cu. ft. In all, 10 wells with 31,490,000 cu. ft. of gas, were drilled. The rock pressure is 80 lb. At present no arrangements for an outlet have been made.

In Platte County, the Prairie Point gas pool in sec. 7, T. 51 N., R. 33 W., and sec. 12, T. 51 N., R. 34 W., and the Lakeside pool in secs. 5 and 6, T. 50 N., R. 33 W., were further developed, and in the latter both oil and gas have been found, but data are not available for publication at this time.

Drilling for gas continued in proven areas in Clay County, and for both oil and gas in proven areas in Jackson and Cass Counties. Table 1 summarizes the results of drilling in Missouri in 1940.

Table 1.—*Wells Drilled for Oil and Gas in Missouri in* 1940

County	Number of Gas Wells	Gas Production, Cu. Ft.	Number of Oil Wells	Oil Production, Bbl.[a]	Dry
Adair					2
Bollinger					1
Buchanan					2
Butler					1
Caldwell	10	31,490,000			9
Carroll					1
Cass	4	1,544,000	3	28	12
Clay	5	1,431,000			4
DeKalb					3
Holt					1
Jackson	5	415,000	1	10	6
Knox					1
Lafayette					2
Livingston					2
Mercer					1
Platte	6	2,775,000	1	10	7
Randolph					1
Schuyler					2
Shelby					1
Totals	30	37,655,000	5	48	59

[a] Partly estimated.

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Petroleum Development in Nebraska in 1940

By E. C. Reed*

Oil was discovered in Nebraska on Nov. 1, 1939, when the Pawnee Royalty Company's Boice No. 1 well, about 3 miles west of Falls City (NE¼ NE¼, sec. 18, T.1 N., R.16 E., Richardson County) was drilled into the Hunton formation but the development of the area took place during 1940. After a pumping test lasting 18 days, the Boice well stopped producing and failed to qualify for the State bonus of $15,000 offered for the first oil well to produce 50 bbl. per day for 60 consecutive days. On May 9, 1940, the Pawnee Royalty Company's Bucholz No. 1 well was completed about ½ mile southeast of the discovery well and flowed at the rate of about 330 bbl. per day, easily meeting the State bonus requirements.

In addition to the discovery well, which later was reconditioned, and the bonus well, 28 producers were drilled in the Falls City field during 1940. Of these wells, 23 are in sec. 20, two are in the northern part of sec. 29, two in the southwestern part of sec. 17 and three in the eastern part of sec.

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Table 1.—*Oil and Gas Production in Nebraska*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
1	Dawson Field, *Richardson*	1940	20	0	1,400	1,400	0	0	1	1	0	1	0	0
2	Falls City, *Richardson*	1939	770	0	272,800	271,000	0	0	28	27	0	1	27	0
3	Shubert Field, *Richardson*	1940	40	0	2,280	2,280			1	1	0	0	1	0
4	Total		830		276,480	274,680			30	29	0	2	28	0

Line Number	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1		1	21.7	?	Hunton	Dev	D	Cav	2,256	2,260	4	A	Granite (during 1937)	3,424
2	5	22	31.5	37/100	Hunton	Dev	D	Cav	2,250	2,270	20	A	Arbuckle	3,372
3	0	1	31	?	Hunton	Dev	D	Cav	2,433	2,452	9	A	Hunton	2,452
4	5	24												

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE 2.—*Summary of Drilling Operations in Nebraska*

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Surface Formation
		Sec.	Twp.	Rge.		
1	Cass	SE SE 8	11 N	13 E		Pleistocene on Pennsylvanian
2	Dakota	NW NE 33	28 N	8 E		Recent Alluvium on Cretaceous-Graneros
3	Dawes	SW NW 1	33 N	50 W		Cretaceous-Pierre
4	Fillmore	NE NE 22	5 N	1 W		Pleistocene on Cretaceous-Greenhorn
5	Furnas	NW NW 33	2 N	21 W		Pleistocene on Cretaceous-Niobrara
6	Gage	SW SW 2	4 N	6 E		Pleistocene on Lower Permian
7	Keith	NW NW 21	14 N	37 W	3,650	Pleistocene on Tertiary-Ogallala
8	Keith	C SW 27	16 N	39 W		Pleistocene on Tertiary-Ogallala
9	Lancaster	SW SW 5	7 N	7 E		Pleistocene on Lower Permian
10	Morrill	SE SE 10	23 N	49 W		Pleistocene on Tertiary-Ogallala
11	Nemaha	NE NE 9	4 N	14 E		Pleistocene on Lower Permian
12	Nemaha	SE SW 16	4 N	15 E	2,713	Pleistocene on Lower Permian
13	Nemaha	NE SW 26	4 N	15 E	2,732	Pleistocene on Lower Permian
14	Nemaha	SE SE 19	4 N	16 E	2,587	Pleistocene on Lower Permian
15	Nemaha	SE NE 35	4 N	16 E		Pleistocene on Upper Pennsylvanian
16	Nemaha	NW NW 8	5 N	14 E	3,110	
17	Nemaha	NW NW 17	5 N	13 E	2,472	
18	Nemaha	NE SW 20	5 N	14 E	Drilling	
19	Nemaha	SE SE 25	5 N	14 E	1,357	
20	Nemaha	NE NE 15	5 N	15 E	3,504	Pleistocene on Lower Permian
21	Nemaha	NW NE 32	5 N	15 E	3,510	
22	Nemaha	SE SE 34	5 N	15 E	2,518	
23	Nemaha	NW NE 26	6 N	13 E		
24	Nemaha	SW NW 36	6 N	14 E		
25	Otoe	SW SW 15	8 N	14 E	724	Pleistocene on Upper Pennsylvanian
26	Pawnee	NE NE 12	1 N	9 E		Pleistocene on Lower Permian
27	Pawnee	NE NE 31	3 N	11 E	735	Pleistocene on Lower Permian
28	Pawnee	NE NE 14	3 N	12 E	740	Pleistocene on Lower Permian
29	Sarpy	SW SE 15	13 N	12 E		Pleistocene on Pennsylvanian
30	Richardson	SW NE 22	1 N	13 E	3,142	Upper Pennsylvanian
31	Richardson	SW NW 6	1 N	14 E	2,310	Alluvium on Lower Permian
32	Richardson	SE SW 8	1 N	14 E		Alluvium on Lower Permian
33	Richardson	SE SE 9	1 N	14 E	2,260	Lower Permian
34	Richardson	NW NE 16	1 N	14 E	2,341	Lower Permian
35	Richardson	NW NE 22	1 N	14 E	2,408	Lower Permian
36	Richardson	NE SE 3	1 N	15 E	2,605	Alluvium on Lower Permian
37	Richardson	NE NW 5	1 N	15 E	3,398	Pleistocene on Lower Permian
38	Richardson	NW NW 24	1 N	15 E	3,760	Lower Permian
39	Richardson	SE SW 6	1 N	16 E		Pleistocene on Lower Permian
40	Richardson	SW NW 8	1 N	16 E		Pleistocene on Lower Permian
41	Richardson	NE SE 8	1 N	16 E	2,404	Pleistocene on Lower Permian
42	Richardson	SE NW 16	1 N	16 E	2,393	
43	Richardson	NW SW 17	1 N	16 E	2,232	
44	Richardson	NW NW 17	1 N	16 E		
45	Richardson	SE NW SW 17	1 N	16 E	2,225	
46	Richardson	NW NE 18	1 N	16 E	2,278	
47	Richardson	NE SE 18	1 N	16 E	2,293	
48	Richardson	SW NW NE 20	1 N	16 E	2,263	
49	Richardson	NE NW NE 20	1 N	16 E	2,282	
50	Richardson	SE NW NE 20	1 N	16 E	2,268	
51	Richardson	SE NE NW 20	1 N	16 E	2,236	
52	Richardson	SE NW NW 20	1 N	16 E	2,245	
53	Richardson	SW NE NW 20	1 N	16 E	2,257	
54	Richardson	SW NW NW 20	1 N	16 E	2,259	Alluvium on Upper Pennsylvanian
55	Richardson	NW SE NW 20	1 N	16 E	2,260	
56	Richardson	NE SE NW 20	1 N	16 E	2,263	
57	Richardson	NW SW NE 20	1 N	16 E	2,263	
58	Richardson	C S_2 NE 20	1 N	16 E	2,270	
59	Richardson	C 20	1 N	16 E	2,229	
60	Richardson	NE SW NW 20	1 N	16 E	2,873 P.B. 2,303	
61	Richardson	NE NW SW 20	1 N	16 E	2,267	
62	Richardson	NW SW NW 20	1 N	16 E	2,271	
63	Richardson	SW SE NE 20	1 N	16 E	2,258	
64	Richardson	SW NE SE 20	1 N	16 E	2,263	
65	Richardson	C SE SW 20	1 N	16 E		
66	Richardson	CWL NW SE 20	1 N	16 E	2,259	

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day Oil, U. S. Bbl.	Remarks
1	Viola	Goldenrod Oil Co.		Drilling
2	St. Peter sandstone	Peder Skriver et al.		Drilling
3	Permian	Stephens Oil Co.		Drilling
4	Arbuckle	Will Ebke		Drilling
5	Cretaceous	L. W. Trickett		Drilling
6	Lower Permian	S. F. Miller		Drilling
7	Permian	California-Nebraska Oil Co.		Dry and abandoned
8	Tertiary-White River	E. A. Keyes et al.		Drilling
9	Silurian	August Krueger		Drilling
10	Cretaceous-Lakota	C. L. Price et al.		Drilling
11	Mississippian	Frank Engles et al.		Drilling
12	Hunton	Black Gold Operating Co.		Dry and abandoned
13	Hunton	Clampitt, Ogden, Richards		Dry and abandoned
14	Hunton	Jackson, Rust et al.		Dry and abandoned
15		Francis Krone et al.		Drilling
16	Viola	Jock Garden et al.		Dry and abandoned
17	Hunton	E. W. Schrock et al.		Dry and abandoned
18		Bow & Arrow Oil Co.		Drilling
19	Pennsylvanian	Black Gold Operating Co.		Dry and abandoned
20	Viola	J. O. Isaacs et al.		Dry and abandoned
21	Arbuckle	Nemaha Development Co.		Dry and abandoned
22	Hunton	Pulliam et al.		Dry and abandoned
23		Continental Petr. Corp. Neb.		Drilling
24		Bow & Arrow Oil Co.		Drilling
25	Pennsylvanian	H. A. Risk		Dry and abandoned
26		Walters et al.		Drilling suspended
27	Granite	Black Gold Operating Co.		Dry and abandoned
28	Granite	Palensky Bros.		Dry and abandoned
29		L. K. Hough et al.		Drilling
30	St. Peter (Ordovician)	Stevens & Uhri		Dry and abandoned
31	Hunton	Eckert & Longmire		Dry and abandoned
32		Uhri Oil Co.		Drilling suspended
33	Hunton	Uhri Oil Co.	50 est.	Cut 50–98 per cent water Producer
34	Hunton	Powers and Stalder		Dry and abandoned
35	Hunton	M. J. Lewis		Dry and abandoned
36	Hunton	Forest City Basin Syndicate		Dry and abandoned
37	Viola	Sparks and Campbell		Dry and abandoned
38	Arbuckle	Pawnee Royalty Co.		Dry and abandoned
39		R. L. McIntyre		Drilling
40		H. S. Campbell et al.		Drilling
41	Hunton	Pawnee Royalty Co.		Dry and abandoned
42	Hunton	Rust, Shaffer et al.		Dry and abandoned
43	Hunton	Pawnee Royalty Co.*	330	Producer
44		Pawnee Royalty Co.*		Drilling suspended
45	Hunton	Pawnee Royalty Co.*	312	Producer
46	Hunton	Taylor Drilling Co.	150	Producer
47	Hunton	Pawnee Royalty Co.*	310	½ per cent water cut. Producer
48	Hunton	Skelly Oil Co.	714	Producer
49	Hunton	Skelly Oil Co.	440	5 per cent water. Producer
50	Hunton	Skelly Oil Co.	350 est.	Producer
51	Hunton	Harper Oil Co.	250–500	Producer
52	Hunton	Harper Oil Co.	360–700	Producer
53	Hunton	Harper Oil Co.	700	Producer
54	Hunton	Harper Oil Co.	1,000	Suspended production, 40 per cent water
55	Hunton	Pawnee Royalty Co.*	600	Producer
56	Hunton	Pawnee Royalty Co.*	600	Producer
57	Hunton	Pawnee Royalty Co.*	800	Producer
58	Hunton	Pawnee Royalty Co.*	840	Producer
59	Hunton	Pawnee Royalty Co.*	840	Producer
60	Viola	Shaffer et al.	150	Producer, 50 per cent water
61	Hunton	Shaffer et al.	150	Producer, 50 per cent water
62	Hunton	Shaffer et al.		Dry and abandoned
63	Hunton	R. L. Campbell et al.	500	Producer
64	Hunton	R. L. Campbell et al.	840	Producer
65		R. L. Campbell et al.		Drilling
66	Hunton	Skelly Oil Co.	700	Producer

* All producing wells of Pawnee Royalty Co. now property of Ohio Oil Co.

18, all in township 1 north, range 16 east, Richardson County. The present proven area of the field is approximately 690 acres, extending for a distance of about 2¼ miles from north-northwest to south-southeast and having a maximum width of about ¾ mile.

The potential production of the field at the close of 1940 is estimated at 10,000 bbl. per day, although estimates as low as 5000 bbl. and as high as 15,000 bbl. have been made. The initial production tests of most of the wells in the field vary from 150 to 1000 bbl. per day.

The thickness of the producing formation varies from 4 to 49 ft. and averages 20 ft. A few wells produce in part from the Misener sand, which immediately overlies the Hunton locally and varies in thickness from zero to about 7 ft. in the field. The gravity of the oil is about 31½° A.P.I. at 60°. The cumulative production of the field up to Jan. 1, 1940 is about 272,000 bbl., the majority being produced during the latter part of this period. Although a number of the wells in the field flowed at first, most of them are now on the pump and the bottom-hole pressure and fluid level have dropped appreciably, especially in the part of the field that has been more closely drilled. A number of the wells are showing some water, varying from none to as high as 80 per cent in unusual cases but averaging approximately 5 per cent for the entire field.

The wells vary in depth from 2225 to 2365 ft. and average 2268 ft. in depth. The depth to the top of the producing formation varies from 2210 to 2361 ft. and averages 2248 ft. Sea-level elevations on the top of the Hunton in the producing area vary from minus 1313 to minus 1390 ft. The oil occurs over the top of a north-northwest trending anticline, which exhibits relatively small closure on surface beds (Upper Pennsylvanian and Lower Permian) but shows a closure of about 200 ft. on the top of the Hunton. The field is now fairly well defined by drilling. The first wells were 40-acre locations but a number of 10-acre locations have been drilled in the central part of the field. Drilling is done almost entirely with rotary tools, although the discovery well was a cable-tool test. About 100 ft. of 10-in. surface casing is cemented and drilling continues to near the top of

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Surface Formation
		Sec.	Twp.	Rge.		
67	Richardson	C SW SE 20	1 N	16 E	2,306	Alluvium on Upper Pennsylvanian
68	Richardson	SE NW SE 20	1 N	16 E	2,252	Alluvium on Upper Pennsylvanian
69	Richardson	SW NE SW 20	1 N	16 E	2,246	Alluvium on Upper Pennsylvanian
70	Richardson	NW SE SE 20	1 N	16 E	2,266	Alluvium on Upper Pennsylvanian
71	Richardson	NE NW NW 20	1 N	16 E	2,365 P. B. 2,335	Alluvium on Lower Permian
72	Richardson	C NW NE 29	1 N	16 E	2,343	Alluvium on Lower Permian
73	Richardson	C SE NE 29	1 N	16 E	2,887	Alluvium on Lower Permian
74	Richardson	C NE NE 30	1 N	16 E	2,632	Alluvium on Lower Permian
75	Richardson	C W line NE-SE 20	1 N	16 E		Alluvium on Upper Permian
76	Richardson	C SW SW 5	2 N	13 E		Pleistocene on Upper Pennsylvanian
77	Richardson	NE SE 3	2 N	15 E	2,473	Pleistocene on Lower Permian
78	Richardson	NE NW 4	2 N	16 E	2,550	Pleistocene on Lower Permian
79	Richardson	NW SE 31	2 N	16 E	2,595	Pleistocene on Lower Permian
80	Richardson	C SW SW 35	2 N	16 E	2,503	Pleistocene on Lower Permian
81	Richardson	NE SE 19	3 N	16 E	2,651	Pleistocene on Lower Permian
82	Richardson	C NE SW 29	3 N	16 E	2,452	Pleistocene on Upper Pennsylvanian
83	Richardson	C SE NW 29	3 N	16 E	2,561	Pleistocene on Lower Permian
84	Richardson	E½ NW NW 31	3 N	16 E		Pleistocene on Lower Permian
85	Scotts Bluff	SE NE 33	23 N	57 W		Alluvium on Oligocene-White River Cretaceous-Pierre
86	Scotts Bluff	SE SE 35	23 N	58 W		Alluvium on Oligocene-White River Cretaceous-Pierre

the Hunton without coring. It is general practice to core the top of the producing formation and to cement 7-in. casing on top or a foot or two into the producing formation. The wells are then drilled in with a cable-tool machine and almost all of them are acid-treated, using from 500 to 2000 gal. of acid per well. Some operators use, with considerable success, a butane treatment of 500 gal. introduced ahead of the acid. The acid is usually introduced under a hole full of oil load. Swabbing after acid treatment is the general practice. Many of the wells are pumped through 2-in. or 3-in. tubing, although some casing pumps are in operation. One well in the field is cased through the producing formation and gun-perforated, but this practice is not generally followed because of water difficulties.

Only two wells in the producing area have tested formations lower than Hunton, one having tested the Viola and the other the Arbuckle. Shows in the Viola have been found but no production has yet developed at that horizon.

Twenty wells outside of the Falls City field were drilled in Richardson County, 16 of these being tests of the Hunton; one tested Viola, one tested Simpson, and the third Arbuckle. Production was found in two of these tests; i.e., the Indian Territory Illuminating Oil Company's Schaible-Kuttler No. 1 (NE.SW. sec. 29, T.3 N., R.16 E.) and the Uhri Oil Company's Ogle No. 1 (SE.SE. sec. 9, T.1 N., R.14 E.). Eleven wells were drilled in Nemaha County without securing production. One was a Pennsylvanian test, six were Hunton tests, two were Viola and two were Arbuckle. Two granite wells were drilled in Pawnee County and there was scattered drilling, but no official completions, over the rest of the state.

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day Oil, U. S. Bbl.	Remarks
67	Hunton	Skelly Oil Co.	700	Producer
68	Hunton	Skelly Oil Co.	618	Producer
69	Hunton	Skelly Oil Co.	1,000 est.	Producer
70	Hunton	Kirk and Ross	?	Producer
71	Hunton	Midland Oil Co.	100	Producer
72	Hunton	R. L. Campbell et al.	520	Producer
73	Silurian	Skelly Oil Co.		Temporarily abandoned
74	Hunton	Jackson, Rust et al.		Dry and abandoned
75		Ohio Oil Co.		Drilling
76		J. E. Palensky et al.		Drilling
77	Hunton	I. T. I. O. Co.		Temporarily abandoned
78	Hunton	E. V. Jackson et al.		Dry and abandoned
79	Hunton	Liberty Devel. Co.		Dry and abandoned
80	Hunton	E. V. Jackson and Carlock		Dry and abandoned
81	Hunton	I. T. I. O. Co.		Dry and abandoned
82	Hunton	I. T. I. O. Co.	300	Producer
83	Hunton	E. J. Shaffer et al.		Dry and abandoned
84		W. H. Martgan et al.		Drilling
85		J. H. Sheaffer et. al.		Drilling suspended
86		Fairey Petroleum Co.		Drilling suspended

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	3	23
Number of oil wells completed during 1940	27	2
Number of gas wells completed during 1940	0	0
Number of dry holes completed during 1940		31

Oil and Gas Development in New Mexico in 1940

By A. Andreas*

New Mexico established an annual record by producing 38,897,741 bbl. of oil during 1940. This was approximately 6 per cent greater than the 1939 production of 36,746,840 bbl. The daily average production was 106,569 bbl. New Mexico retained its position as the seventh oil-producing state.

The recommendations of the United States Bureau of Mines were followed by the Oil Conservation Commission in setting the monthly state allowable. At the beginning of the year the average top allowable for each 40-acre unit was 40 bbl. and at the close of the year it was 36 bbl.

Remedial work by the operators has been extremely beneficial and satisfactory in reducing the gas-oil ratios in various fields. Gas formerly blown into the air is now being processed by numerous casinghead plants. The Oil Conservation Commission, with the full cooperation of the Proration Office and operators, has taken bottom-hole pressure surveys and has done considerable remedial work in various fields.

Two new oil fields and one gas field were discovered in New Mexico during 1940. Numerous extensions to the existing fields were made. Some of these were definitely wildcats in the same townships designated as fields and some, although called extensions, were more than 3 miles from production.

Lea County continued to be the largest oil-producing county in the state, with a production of 33,976,394 bbl. It had the largest number of completions during 1940, with 303 oil wells, 9 gas wells and 13 dry holes—a total of 325 wells.

Eddy County was the next most active county, with 239 completions, of which 163 were oil wells, 8 gas wells and 68 dry holes. It produced 4,405,158 bbl. of oil during the year.

The increased activity in Eddy County and the completion of a large number of producing oil wells have created a transportation problem that can be solved only by additional pipe-line facilities. During the year Eddy County was unable to produce 1,500,000 bbl. of its allowable oil, because there was no pipe-line outlet.

There were 601 wells completed in New Mexico in 1940, of which 478 were oil wells, 22 gas wells and 101 dry holes. This was a decline of approximately 9.5 per cent in the number of completions compared with 1939, when 659 wells were drilled.

Southeastern New Mexico

Lea County.—The largest producing field in Lea County was the Monument field, with 6,894,475 bbl.; followed by Eunice with 6,559,348 bbl. and Vacuum with 4,743,065 bbl. The Hobbs pool, which for years was the largest producing field in the state of New Mexico, was fourth with 3,790,477 bbl. The Vacuum pool was the most active area, having 68 completions, of which 67 were oil wells and one was a dry hole. Only one new field was discovered in Lea County during 1940; the discovery well was in the Caprock area, the Livermore State No. 1, in the SE. ¼ SE. ¼ sec. 30, T. 12 S, R. 32 E. This well was drilled to a

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TABLE 1.—*Oil and Gas Production in New Mexico*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
1	Arrowhead, *Lea*	1938	3,680	1,880	1,592,005	1,065,147
2	Artesia, *Eddy*	1923	6,320	160	4,447,955	157,155
3	Aztec-Bloomfield, *San Juan*	1924	90	0	39,753	2,286
4	Barber, *Eddy*	1936	400	40	69,379	25.580
5	Black River, *Eddy*[1]	1937	80	0	2,872	0
6	Blanco, *San Juan*	1929	40	40	1,375*y*	46*y*
7	Caprock, *Lea*	1940	40	0	0	0
8	Comanche, *Chaves*	1936	120	0	5,430*y*	3,930
9	Cooper, *Lea*	1929	4,160	160	12,061,034	1,151,957
10	Corbin, *Lea*	1938	80	0	10,778	9,409
11	Dayton, *Eddy*	1940	240	40	8,670	8,670
12	Eaves, *Lea*	1929	760	120	1,317,958	253,522
13	Eunice, *Lea*	1928	20,160	18,240	46,954,054	6,559,347
14	Fulcher Basin, *San Juan*	1934	0	500*y*	0	0
15	Getty, *Eddy*	1928	240	0	553,177	0
16	Grand Plains, *Chaves*	1939	40	0	500*y*	0
17	Grayburg-Jackson, *Eddy*	1936	6,200	120	8,739,357	1,742,360
18	Halfway, *Lea*	1939	280	0	65,670	65,670
19	Hardy, *Lea*	1935	5,000	200	3,151,730	1,097,853
20	High Lonesome, *Eddy*	1939	280	160	8,744	7,844
21	Hobbs, *Lea*	1928	10,080	10,040	93,783,770	3,790,476
22	Hogback, *San Juan*	1922	160	0	2,025,429	74,503
23	Hospah, *McKinley*	1927	160	0	190,582	163,781
24	Jal, *Lea*	1927	1,360*y*	520	6,100,449	164,454
25	Kuts Canon, *San Juan*	1927	0	2,520	0	0
26	Langlie, *Lea*	1927	5,360	560	5,370,170	1,591,594
27	Leonard, *Eddy*	1929	1,800	400	1,016,879	288,445
28	Loco Hills, *Eddy*	1939	5,760	80	2,252,337	1,921,467
29	Lynch, *Lea*	1929	440	0	5,888,711*y*	156,777
30	Lynn, *Lea*	1929	1,480	120	977,160	299,676
31	Maljamar, *Lea*	1926	3,680	0	2,157,728*y*	775,008
32	Mattix, *Lea*	1936	6,040	360	4,688,498	1,686,735
33	McMillan, *Eddy*	1938	40	0	308	14
34	Monument, *Lea*	1934	19,760	16,080	38,837,354	6,894,475
35	North Lynch, *Lea*	1929	80	0	1,022,648*y*	10,596
36	North Maljamar, *Lea*	1939	40	0	1,782	956
37	Penrose, *Lea*	1935	7,380	5,120	5,727,509	1,578,647
38	Rattlesnake, *San Juan*	1924	640	0	4,420,783	137,048
39	Red Lake, *Eddy* (deep horizon)	1924	1,160*y*	680	331,272	76,875
40	Red Lake, *Eddy* (shallow horizon)	1939	440*y*	0	30,489	21,475
41	Red Mountain, *McKinley*	1933	20	0	4,650*y*	750*y*
42	Rhodes, *Lea*	1928	880	400	253,447	57,540
43	Robinson, *Eddy*	1926	520	40	334,085	88,657
44	Shugart, *Eddy*	1938	1,080	0	262,881	166,262
45	Skaggs, *Lea*	1936	120	0	52,048	24,433
46	Skelly, *Lea*	1936	3,200	2,440	2,149,418	589,000
47	South Eunice, *Lea*	1930	3,800	200	3,872,540	832,673
48	South Lovington, *Lea*	1938	1,440	40	657,266	478,269
49	South Maljamar, *Lea*	1939	80	0	7,892	7,892
50	Table Mesa, *San Juan*	1925	100	0	538,157	33,845
51	Ute Dome, *San Juan*	1921	0	640	0	0
52	Vacuum, *Lea*	1929	13,480	0	8,479,288	4,743,065
53	West Eunice, *Lea*	1928	400	0	152,604	91,206
54	Total		139,190*y*	61,900*y*	270,618,575*y*	38,897,370*y*

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Field abandoned during 1939.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: During 1940: Abandoned	Number of Oil and/or Gas Wells: End of 1940: Temporarily Shut Down	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Number of Oil and/or Gas Wells: End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]
1	2,481	1,446	92	44	0	0	92	0	92	0	1,460	1,427	0
2	1,793	65	180*y*	1	*y*	0	169	0	0	169	*y*	*y*	0
3	0	0	30	0	6*y*	*y*	10	0	0	10	*x*	0	0
4	0	0	10	2	0	2	8	0	0	9	550	550	0
5	0	0	2	0	2	0	0	0	0	0	*x*	*x*	0
6	261	34	1	0	0	0	0	1[a]			1,200	1,000	0
7	0	0	1	1	0	1	0	0	0	1	*x*	*x*	0
8	0	0	3	1	0	0	3	0	0	3	0	0	0
9	99,417	5,263	108	4	*y*	0	87	3	35	52	1,398	*x*	0
10	0	0	2	1	0	0	2	0	0	2	*x*	*x*	0
11	4	4	7	7	0	0	6	1	6	0	*x*	*x*	0
12	6,618	246	22	0	0	0	19	3	9	10	*x*	*x*	0
13	193,316	19,414	507	9	0	3	489	0	436	53	1,400	1,056	0
14	217	48	3	2	0	0	0	3			576	576	0
15	0	0	9	0	0	9	0	0	0	9	0	0	0
16	0	0	1	0	0	1	0	0	0	1	*x*	*x*	0
17	8,739	1,742	164	29	0	0	163	1	128	35	*x*	*x*	0
18	*x*	*x*	7	5	1	0	6	0	2	4	*x*	*x*	0
19	11,796	4,093	125	10	0	0	120	0	101	19	1,400	1,320	0
20	110	110	11	8	0	1	6	4	0	7	*x*	*x*	0
21	199,836	4,710	266	0	0	0	263	0	234	29	1,550	1,189	0
22	0	0	7	0	0	0	7	0	7	0	200*x*	100	0
23	0	0	13	7	0	0	13	0	0	13	*x*	*x*	0
24	32,021	5,137	47	1	0	9	20	2	5	15	*x*	*x*	0
25	10,975	1,952	17	2	0	0	0	17			265	420	0
26	41,756	19,823	149	8	0	0	124	19	118	6	1,450	*x*	0
27	610	173	55	22	*y*	2	45	8	33	12	*x*	*x*	0
28	1,351	1,153	149	76	*y*	7	140	2	123	24	950	737	0
29	0	0	16	0	0	0	11	0	0	11	1,295	0	0
30	5,249	2,902	40	6	0	0	27	6	21	6	1,365	*x*	0
31	15,000*y*	1,893	99	60	0	0	83	0	74	9	*y*	*y*	0
32	21,090	9,961	168	19	0	0	150	8	136	14	1,400*y*	*x*	0
33	0	0	1	0	0	1	0	0	0	1	0	0	0
34	109,659	14,958	502	2	0	2	493	0	478	15	1,427	1,307	0
35	32	3	2	0	0	0	2	0	0	2	0	0	0
36	0	0	1	0	0	0	1	0	0	1	0	0	0
37	26,369	8,425	187	24	0	0	186	0	166	20	*x*	*x*	0
38	0	0	78	4	5	3	41	0	0	44	*x*	*x*	0
39	133	30	46*y*	2	0	0	19	17	0	19	*x*	*x*	0
40	12	9	11	9	0	0	11	0	0	11	*x*	*x*	0
41	0	0	7	0	0	0	6	0	0	6	0	0	0
42	30,174	9,026	32	6	0	0	10	12	8	2	1,397	*x*	0
43	134	35	14	2	0	0	13	1	0	13	*x*	*x*	0
44	106	68	27	13	*y*	3	24	0	17	10	*x*	*x*	0
45	170	55	3	0	0	0	3	0	1	2	*x*	*x*	0
46	7,093	3,466	89	21	0	0	72	4	54	18	1,420	1,326	0
47	14,062	3,512	98	15	0	0	73	0	71	2	1,455	1,450	0
48	461	220	37	3	0	0	34	1	31	3	1,670	1,500	0
49	0	0	2	1	0	0	2	0	0	2	0	0	0
50	0	0	6	0	0	0	6	0	0	6	*x*	*x*	0
51	6,469	887	3	0	0	0	0	3			720	560	0
52	7,403	2,876	368	67	0	0	337	0	305	32	1,630	*y*	0
53	0	0	9	5	0	0	9	0	0	9	1,300	1,220	0
54	854,917*y*	123,739*x*	3,834*y*	499	14*y*	44*y*	3,405	116	2,691	741			

[a] Small amount of oil produced from this gas well.

TABLE 1.—(*Continued*)

Line Number	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	36	0.001	San Andres	Per	D	Cav	3,720	3,800	80	A	San Andres Per	3,870
2	29.5	0.002	San Andres	Per	LS	x	1,823	2,005	x	AM	San Andres Per	4,035
3	55	0.010	Farmington sand	CreU	S	x	750	1,075	25	S	Lewis Shale CreU	2,665
4	20.5	0.001	Capitan	Per	L	Cav	1,459	1,466	x	A	Capitan Per	1,953
5	39.5	0.001	Delaware sand	Per	S	x	2,406	2,545	x	MF	Delaware Per	2,885
6	54	0.130	Mesa Verde and Pictured Cliffs	CreU	S	x	4,250	4,550	x	H	Mesa Verde CreU	4,550
7	36	0.001	San Andres	Per	S	x	3,025	3,052	10	A	San Andres Per	4,385 PB 3,052
8	28.5	0.001	San Andres	Per	S	x		1,283		ML	Capitan Per	1,400
9	29	0.001	White lime	Per	D	Cav	3,542	3,608		A	Lower San Andres Per	5,095
10	30.5	0.001	White lime and sand	Per	LS	x	4,258	4,319		A	San Andres Per	5,118 PB 4,319
11	36	0.001	San Andres	Per	LS	Fis	1,022	1,105	29	A	San Andres Per	2,545
12	28.5	0.002	Permian sand	Per	S	x	3,175	3,300	100	A	San Andres Per	3,542
13	35.1	0.002	White lime	Per	D	Cav	3,800	3,882	82	A	San Andres Per	4,404
14			Pictured Cliffs	CreU	S	x	1,700	1,740	40	H	Pictured Cliffs CreU	1,989
15	24	0.001	Capitan	Per	LS	x	1,365	1,380	15	A	Permian	6,683
16	34	0.001	San Andres	Per	S	x	1,000	1,018	18	A	San Andres Per	1,018
17	37	0.001	Permian sand and White lime	Per	LS	Cav	3,779	3,827	48	A	San Andres Per	4,383
18	28.6	0.001	White lime	Per	L	Cav	2,590	2,629	39	A	San Andres Per	4,005
19	32.5	0.002	Permian sand and White lime	Per	SD	Cav	3,710	3,763	53	A	San Andres Per	3,872
20	36.2	0.003	San Andres	Per	LS	x	2,500	2,542	42	A	San Andres Per	3,744
21	35.4	0.001	White lime	Per	D	Cav	4,050	4,174	123	A	San Andres Per	4,500
22	60	0.001	Dakota sand	CreU	S	x	705	714	9	D	McElmo CreL	1,225
23	29.7	0.025	Hospah sand	CreU	S	x	1,640	1,651	11	DF	Dakota CreU	3,282
24	36	0.002	White lime	Per	D	Cav	3,303	3,334	31	A	San Andres Per	4,125
25	0	0	Pictured Cliffs	CreU	S	x	1,840	1,900	60	H	Mesa Verde CreU	4,400
26	28	0.001	Permian sand	Per	S	x	3,350	3,530	x	A	San Andres Per	4,385
27	28.5	0.001	Permian sand and White lime	Per	S	x	2,779	2,860	x	A	San Andres Per	3,591
28	35	0.001	Permian sand	Per	S	x	2,415	2,900	x	A	San Andres Per	3,860
29	30	0.001	White lime	Per	D	Cav	3,760	3,777	17	A	San Andres Per	4,046
30	33	0.001	Permian sand and White lime	Per	D	Cav	3,550	3,797	x	A	San Andres Per	5,095
31	32	0.001	White lime	Per	L	x	3,990	4,109	x	A	San Andres Per	4,390
32	32	0.001	Permian sand	Per	S	x	3,500	3,559	59	A	San Andres Per	4,200
33	29	0.001	Carlsbad	Per	S	x	1,150	1,180	30	A	San Andres Per	3,305
34	35	0.001	White lime	Per	D	Cav	3,829	3,939	90	A	San Andres Per	4,534
35	30	0.001	White lime	Per	D	Cav	3,760	3,777	17	A	San Andres Per	4,046
36	31	0.001	White lime	Per	D	x	3,875	4,015	75	A	San Andres Per	4,097
37	34	0.001	Permian sand	Per	S	x	3,550	3,667	90	A	San Andres Per	4,705
38	60	0.001	Dakota	CreU	S	x	784	808	24	AF	Ignacio quartzite Cam	7,397
39	29	0.001	Carlsbad	Per	S	x	1,904	1,930	26	A	San Andres Per	2,905
40	29	0.001	San Andres Permian	Per	L	x	476	503	27y	A	San Andres Per	2,905
41	42	0.001	Mesa Verde	CreU	S	x	438	457	13	AF	Mesa Verde CreU	640
42	33	0.001	Permian sand	Per	S	x	3,050	3,375	x	A	San Andres Per	4,115
43	31	0.001	Permian sand and White lime	Per	S	x	3,919	4,009	80	A	San Andres Per	4,359
44	33	0.001	Permian sand	Per	S	x	3,454	3,775	x	A	San Andres Per	4,340
45	30	0.001	White lime	Per	L	x	3,800	3,860	0	A	San Andres Per	4,757
46	32.5	0.001	Permian sand	Per	S	x	3,525	3,663	x	A	San Andres Per	4,052
47	29.5	0.001	White lime	Per	D	Cav	3,775	3,845	x	A	San Andres Per	6,202
48	33	0.001	White lime	Per	L	x	4,730	5,112	x	A	San Andres Per	5,302
49	33.5	0.001	White lime	Per	L	x	4,120	4,152	x	A	San Andres Per	4,383
50	56.5	0.001	Dakota sand	CreU	S	x	1,325	1,337	7	A	Chinlee-TriU	3,010
51	0	0	Dakota	CreU	S	x	2,285	2,350	60	D	Dakota Sand CreU	2,350
52	35.5	0.001	White lime	Per	D	Cav	4,418	4,684	200y	A	San Andres Per	5,329
53	31	0.001	White lime	Per	L	x	3,793	3,847	x	A	San Andres Per	4,695
54												

total depth of 4385 ft. and plugged back to 3052 ft. It is pumping 16 bbl. of oil and 9 bbl. of water per day. The oil is 36° gravity and the producing horizon is in the San Andres formation of Permian age. The well is now shut in because of lack of pipe-line facilities. The area is 25 miles north of the nearest production, which is in the North Maljamar area.

Eddy County.—Loco Hills continued to be the most active area, with 91 completions, 74 oil wells, 2 gas wells and 15 dry holes; also, it was the largest producing field in Eddy County, with a production of 1,921,467 bbl.

The second new oil field discovered in New Mexico during the year was the discovery well of the Dayton area, Eddy County, drilled by Martin Yates, Jr. This well was the McCall No. 1, in SW. ¼ SW. ¼ sec. 26, T. 18 S, R. 26 E. It was completed at a total depth of 1033 ft. Top of the pay was encountered at 1022 ft. in a sandy lime of the San Andres formation of Permian age. The initial production of this flowing well was 100 bbl. daily. The area is 4 miles southwest of the western edge of the old Artesia pool.

Chaves County.—The first new field discovered in New Mexico during the year was a gas field in Chaves County. This well was drilled by Harvey Yates in NE. ¼ NW. ¼ sec. 24, T. 15 S, R. 28 E. It was drilled to a total depth of 3285 ft. and plugged back to 1500 ft. This well was completed in February for an 800,000-cu. ft. gas well, the producing horizon being in the San Andres formation of Permian age. This area in Chaves County is 6 miles north of the High Lonesome pool.

The Comanche field, in T. 11 S, R. 26 E, Chaves County, produced 3930 bbl., which was transported by trucks to local refineries. Some wildcatting was done but results were disappointing.

TABLE 2.—*Summary of Drilling Operations in New Mexico*

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Surface Formation
		Sec.	Twp.	Rge.		
1	Chaves	27	13 S	25 E	1,409	Tertiary
2	Chaves	24	15 S	28 E	3,285 PB 1,500	Tertiary
3	Chaves	25	15 S	29 E	3,830	Tertiary
4	Eddy	36	16 S	24 E	2,552	Tertiary
5	Eddy	24	16 S	28 E	2,605	Tertiary
6	Eddy	31	16 S	29 E	2,652	Tertiary
7	Eddy	33	16 S	29 E	2,852	Tertiary
8	Eddy	13	16 S	30 E	3,744	Tertiary
9	Eddy	25	16 S	30 E	3,082	Tertiary
10	Eddy	14	17 S	24 E	1,282	Tertiary
11	Eddy	12	17 S	29 E	2,563	Tertiary
12	Eddy	24	18 S	23 E	1,740	Tertiary
13	Eddy	26	18 S	26 E	1,033	Tertiary
14	Eddy	4	19 S	30 E	3.421	Tertiary
15	Eddy	14	20 S	26 E	625	Tertiary
16	Eddy	6	20 S	27 E	817	Tertiary
17	Eddy	12	23 S	25 E	1,740	Tertiary
18	Eddy	18	23 S	26 E	1,808	Tertiary
19	Lea	30	12 S	32 E	4,385 PB 3,052	Tertiary
20	Lea	26	13 S	37 E	6,300	Tertiary
21	Lea	11	20 S	34 E	3,861	Tertiary
22	Lea	20	21 S	38 E	4,710	Tertiary
23	Lea	25	22 S	37 E	4,500	Tertiary
24	Rio Arriba	22	31 N	1 W	2,373	Cretaceous
25	San Miguel	32	16 N	12 E	1,822	Permian

Northwestern New Mexico

There was not much drilling in the northwestern part of the state during the year. Several wells were drilled on the Rattlesnake structure, one being the Continental Oil Company's Rattlesnake No. 100, drilled to a total depth of 7397 ft., which was completed Jan. 23, 1940. The Pennsylvanian section, from 6724–6732 ft., showed about 100 bbl. of oil and 400 bbl. of water. The deepest horizon encountered by this test was believed to have been the Ignacio quartzite of Cambrian age.

Two more gas wells were drilled in the Fulcher Basin field, T. 29 N, R. 12 W. Gas from the field is connected by pipe line to the Kutz Canon gas field, which supplies gas for Albuquerque, Santa Fe, and intermediate points.

The Atlantic Refining Co. did considerable seismograph work in the Blanco-Bloomfield area but as yet has drilled no tests.

A test well drilled by the Continental-Hughes Oil Co. on the Dulce dome, T. 31 N., R. 1 W., was a disappointment. The objective horizon, the Dakota sandstone, encountered water at 2340 ft. The total depth of this well was 2373 feet.

San Juan County produced 247,728 bbl. and McKinley County produced 164,531 bbl., from the Hospah dome, making a

Table 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks (Note Dry Holes Here)
			Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	San Andres-Perm.	T. S. Stanfield						Dry hole
2	San Andres-Perm.	Harvey Yates et al.		0.8		y	y	Gas well (aban. 1940)
3	San Andres-Perm.	Sam Sanders						Dry hole
4	San Andres-Perm.	Gene R. Burke						Dry hole
5	San Andres-Perm.	C. L. Tallmadge et al.						Dry hole
6	San Andres-Perm.	C. B. Buck	45-P			y	y	Ex. H. L. area
7	San Andres-Perm.	Schumaker & Richey	10-P					Ex. H. L. area
8	San Andres-Perm.	Thomas & Bowers	13-P					Ex. H. L. area
9	San Andres-Perm.	Ets Brothers et al.		2.4				Ex. H. L. area
10	San Andres-Perm.	Artesia Drilling Co.						Dry hole
11	San Andres-Perm.	Mac T. Anderson	90-F		Open 2″	y	y	Discovery N. Leonard
12	San Andres-Perm.	May Weathers						Dry hole
13	San Andres-Perm.	Martin Yates Jr. et al.	100-F		Open 2″	300	y	Discovery Dayton
14	San Andres-Perm.	J. W. Elliott						Dry hole
15	San Andres-Perm.	Knox & Featherstone						Dry hole
16	San Andres-Perm.	A. E. Frasier	Show of oil					Dry hole
17	Delaware-Perm.	Turner & De Vito	1200 ft.	Sulphur water in hole				Dry hole
18	San Andres-Perm.	E. P. Moran						Dry hole
19	San Andres-Perm.	Geo. P. Livermore	16 BO + 9 BWPD-pump					Discovery Caprock
20	Delaware-Perm.	Ventura Oil Co.						Dry hole
21	San Andres-Perm.	The Texas Company		Hole full salt water				Dry hole
22	San Andres-Perm.	Stanley Weiner et al.						Dry hole
23	San Andres-Perm.	Gulf Oil Corporation						Dry hole
24	Dakota-Cre.	Continental-Hughes		Show of gas				Dry hole
25	Magdalena-Penn.	Keith-McCune						Dry hole

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	51	38
Number of oil wells completed during 1940	471	7
Number of gas wells completed during 1940	21	1
Number of dry holes completed during 1940	60	41

total of 412,259 bbl. produced in the San Juan Basin area.

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Petroleum and Natural Gas in New York in 1940

By C. A. Hartnagel*

The production of petroleum in New York in 1940, totaling 4,999,000 bbl., was only slightly under the amount produced in each of the previous three years. The year 1940 started auspiciously with a posted price on Jan. 1 of $2.75 a barrel. Four price reductions, beginning in May, resulted in August in a low of $1.85 a barrel, after which two increases brought the year's closing price to $2.15 a barrel. The favorable crude price at the beginning of the year stimulated an increased drilling program, especially in the water-flooding districts. In the Allegany County region, which accounts for about two-thirds of the state's oil production, 886 wells, including water-intake wells, were drilled; 200 more than in the preceding year. During the closing months of the year there was a marked decline in the number of wells drilled.

The unfavorable position in which the industry found itself before midsummer was due largely to the loss of export markets for its high-grade lubricants, constituting approximately 25 per cent of its business. As a result of this situation, runs to refineries were curtailed as much as 30 per cent at the middle of the year. Improvement in market conditions toward the end of the year found the stocks of available crude at an almost record low.

Deep Drilling

With the gradual exhaustion of some of the important natural and flood-oil-producing areas of the Allegany and Bradford pools, overproduction will not be a serious problem in the future. The possibility of finding new territory or deeper producing sands has been further lessened by the drilling of additional deep wells for gas in and about the present oil fields. Many of these wells drilled to the Oriskany sandstone were over 4000 ft. deep and have tested the entire thickness of the Devonian formation, the upper 2000 ft. of which contain all the important oil-producing strata in the state.

Water-flooding

It is thus evident that the problem of the New York oil producers is not one of finding new supplies but of obtaining as much oil as possible from the old developed fields that during the 60 years of their life have produced 130,000,000 bbl. of oil. Although a few floods were in operation before 1919, when the production of oil by flooding was made legal, the output for that year amounted to only 851,000 bbl. From 1919 on there has been an almost constant increase, which during the past four years has averaged well above 5,000,000 bbl. annually. During the last 22 years, which constitutes the period of important flooding operations, 65,337,000 bbl. of oil have been produced in the state. Careful estimates indicate that between one-third and one-half of the oil fields are being flooded or are already watered out. Some of the flooded and watered-out areas include territory with unusually thick sands, which were highly productive during the early history of the fields. From a recent study of operations in the New York oil fields, it is estimated that about 65,000,000 bbl. of oil

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* State Geologist of New York, Albany, N. Y.

TABLE I.—*Oriskany Wells Completed in New York State in 1940*

County and Township	Name of Well	Elevation, Ft.	Depth to Oriskany Sand, Ft.	Drilled by	Initial Daily Production, M Cu. Ft.	Pressure, Lb. per Sq. In.	Remarks
Allegany County:							
1. Allen	Frances M. Barney	1,636	2,922	Hanley & Bird	300		
2. Allen	E. C. Hoyt	1,585	2,900	Higgins et al.			Dry hole
3. Allen	George Bentley	1,737	3,020	Lawrence Gas Co.	2,875		
4. Allen	Roy Phipps	1,707	3,029	Higgins et al.			S. W.
5. Allen	Margaret Kellogg	1,730	3,010	Hanley & Bird	8,000	1,060	
6. Almond	E. Lorello	1,534	Horizon 3,423?	Penn York	No sand		
7. Andover	Frank Dean	?		Belmont Q. D. Co.			Abandoned at 927 ft.
8. Andover	Michael Lynch	?		Empire G. & F. Co.			Abandoned at 625 ft.
9. Andover	Augustus Lynch	2,274	5,001	G. L. Cabot			S. W.
10. Andover	John Patten	2,219	4,890	Penn York			S. W
11. Andover	H. G. Clark	1,978	4,691	Belmont	4,500	1,930	Also S. W.
12. Andover	Milford Crandall No. 1	2,264	4,877	Empire G. & F. Co.	8,000	1,660	
13. Independence	Albert McLean	2,226	4,942	Empire G. & F. Co.			S. W.
14. Independence	Forsythe Estate	2,256	5,032	Penn York			S. W.
15. Independence	Sam Crandall No. 1	2,285	4,912	Empire G. & F. Co.	1,500	1,590	At 4,917 ft., blew wild, 44 mm.
16. Independence	C. A. Wilson	1,965	4,612	Empire G. & F. Co.	16,000	1,820	
17. Independence	Hazel Atwood	2,292	4,919	Empire G. & F. Co.	6,500	1,600	
18. Independence	Sam Crandall No. 2	2,213	5,058	Empire G. & F. Co.			S. W.
19. Independence	Livermore No. 2	2,049	4,845	Belmont Q. D. Co.			S. W.
20. Independence	Robert Clark No. 2	2,181	4,889	Belmont Q. D. Co.			S. W.
21. Independence	Jay Nye	1,948	4,610	Empire G. & F. Co.	8,000	1,770	
22. Ward	E. S. Hayes	2,161	4,456	Clancy et al.			S. W. for 2,000 ft.
23. Ward	Maud Hayes No. 2	2,214	4,500	Clancy et al.			S. W.
24. Willing	F. Cornelius	2,276	4,949	Empire G. & F. Co.	9,750	625	
25. Willing	Byron Fortner No. 2	2,274	4,942	Cunningham	6,950		
26. Willing	Hilligas No. 4	2,218	4,905	Belmont Q. D. Co.	S. W. & 250	1,120	S. W. but not abandoned
27. Willing	Fortner No. 3	2,268	5,005	Cunningham			S. W.
28. Willing	Pat Luden	2,262	4,956	Cunningham	12,000		
							Allegany Co. initial production, 84,625 M
Steuben County:							
29. Corning	Horton Alger	1,790	3,745	Corning Glass Wks.			Dry hole
30. Erwin	Ellen Collins	1,718	3,802	G. L. Cabot			S. W. dry below Oriskany. Total depth 6,825 ft.
31. Greenwood	Mary Burger	1,871	4,560	Hanley & Bird			S. W.
32. Greenwood	State Land No. 2	2,349	4,831	Empire G. & F. Co.	5,500	405	
33. Greenwood	Stanley Murray	2,313	4,870	Hanley & Bird			S. W.
34. Greenwood	Charles Fisher	2,228	4,804	Hanley & Bird			S. W.
35. Hartsville	Ashbaugh	2,045	4,406	Belmont Q. D. Co.			S. W.
36. Hornellsville	Sarah Hemphill	1,984	3,986	New Penn			S. W.
37. Howard	Jennie Freeborn	1,865	3,669	Penn-York			S. W.
38. Howard	Earl House	1,703	3,394	Leiderbach			Abandoned
39. Jasper	Myra Wallace	1,770	4,238	Sylvania			S. W.
40. Troupsburg	Everett Dearman	1,616	4,872	Acme Dr. Co.			Dry hole
41. West Union	Clara W. Johnson	2,105	5,075	Penn York	80	795	
42. West Union	Sarah Nixon	2,207	5,010	Penn York	8,000	2,040	
							Steuben Co. initial production 13,580 M
Chemung County:							
43. Elmira	Consolidated Brick Co.	1,002	2,849	Belmont Q. D. Co.	1,500	1,505	
44. Elmira	W. W. Gregg No. 1	1,173	3,091	Belmont Q. D. Co.			Dry hole
45. Elmira	C. E. Updegraff	858	2,701	C. E. Updegraff	130		
46. Elmira	Ben Barcus No. 1	849	2,682	Updegraff	1,000		
47. Southport	V. Messing	1,349	3,953	Rogers et al.			Dry hole
48. Veteran	G. W. Wood	1,470	3,171	Belmont Q. D. Co.			Dry hole
							Chemung Co. initial production 2,630 M

TABLE 1.—(*Continued*)

County and Township	Name of Well	Elevation, Ft.	Depth to Oriskany Sand, Ft.	Drilled by	Initial Daily Production, M Cu. Ft.	Pressure, Lb. per Sq. In.	Remarks
Tompkins County					75 M		
49. Caroline.....	DeForest Head	1,071	No sand	Leiderbach et al.			Dry hole
50. Groton......	C. Westfall	1,534	2,139	N. Y. S. Nat. Gas			Dry hole
51. Groton......	Thomas Caslin	1,393		Belmont Q. D. Co.			Abd. at 880′
52. Groton......	Bert Noble	1,397	2,119	N. Y. S. Nat. Gas	75	500	
53. Newfield....	E. S. Van Kirk	1,234	Horizon 2,355?	Leiderbach et al.			No sand
							Tompkins Co—initial production

Total initial Oriskany production, 100,910 M

will be recovered by present flooding methods. With more favorable prices for oil, which may result as the main fields become exhausted, it is quite possible that oil obtained from the thinner sands may raise the total to 100,000,000 barrels.

NATURAL GAS

Drilling for natural gas was active in the Oriskany area along the Pennsylvania border in 1940. Fifty wells were drilled to the Oriskany sandstone, of which 20 were listed as producers. Total daily initial capacity of the wells amounted to 100,910 M cu. ft. In 15 of the producers the daily capacity ranged between 1,000,000 and 16,000,000. One well on the Sam Crandall farm, in Allegany County, blew wild for a period of three weeks. It had an estimated daily capacity of 44,000,000 cu. ft. When brought under control, the daily volume was reported as 1,500,000, the production for this well shown in the state total.

Nearly all of the wells drilled in 1940 were in search of new production, but it is evident that a still wider search will be necessary if a volume of production at all comparable with that of the past few years is to be maintained. While the outlook is not cheerful, discoveries of new supplies lend some encouragement for continued operations. Of the 50 wells drilled to the Oriskany in 1940, only six were put down in old established fields—five in the Beech Hill field, Allegany County, and one in the Greenwood field, Steuben County. Four of the five Beech Hill wells, all of which were in Willing township, proved to be producers, with a combined initial capacity of 28,950 M cu. ft. of gas daily. This represents but 10 per cent less than the initial production from the Beech Hill field in 1939, and about one-third its initial production for 1938, the discovery year. In the old Greenwood field, which has had no new production since 1937, one well, the State Land No. 2, came in with 5500 M cu. ft. of gas. In the remaining Oriskany territory, wildcat drilling prevailed.

In line with the Beech Hill pool to the southwest and the State Land well in Greenwood to the northeast, new production has been found this year to the amount of 40,000 M cu. ft. in Independence and Andover townships. It should be observed that the combined initial production for the year along what might be termed this Beech Hill-Independence-Andover-Greenwood axis totals 75,450 M cu. ft. of gas, or more than three-fourths the entire initial Oriskany production for the year.

The remaining 25,460 M cu. ft. of new gas, or one-fourth the total initial Oriskany production, was produced by one well in the southwestern part of Andover township, Allegany County, three wells in Allen

township, Allegany County, two wells in West Union township, Steuben County, with some smaller flows in Elmira township, Chemung County, and in Groton township, Tompkins County.

New Pipe Line

To augment the diminishing supply of Oriskany gas available for consumption in New York state, a new 117-mile 8-in. pipe line was completed during the year. This line, mostly in Pennsylvania, will connect with lines leading from the gas fields of West Virginia. The New York terminus is near the city of Olean, where the line will connect with the terminus of the Home Gas Co. (old New York Transit) lines that cross the southern tier of counties.

Oil and Gas Development in Ohio in 1940

By Kenneth Cottingham,* Member A.I.M.E.

The number of wells completed in Ohio during 1940 was about 20 per cent more than during the preceding year, the comparative totals being 1020 and 1228. Of the 1940 completions, 327 were oil wells, 491 gas wells, and 410 dry. The completions for the past five years, divided into oil wells, gas wells, and dry holes, are shown in Table 2. Wells drilled deeper and input wells in water-flood areas are not included in the tabulation.

The annual production of oil has decreased steadily in Ohio from the maximum of 23,941,000 bbl. produced in 1896. Table 3 shows the quantities of oil produced in the last five years. In 1940, the total was 3,052,000 bbl., produced by about 25,500 wells. The number of wells and the approximate quantities by grades are shown in Table 1.

Table 1.—*Tabulation by Grade*

Grade	Number of Wells	Barrels
Pennsylvania	12,800	1,198,000
Lima	7,900	325,000
Corning	3,730	1,159,000
Lodi	1,040	359,000
Cleveland	30	11,000
Total	25,500	3,052,000

The prices paid for Ohio crude oil in 1940, together with dates of changes in posting, are shown in Table 4.

The production of natural gas in Ohio has declined from a maximum of 79,510,032 M cu. ft. in 1915 to 36,469,000 M cu. ft. in 1939, the most recent year for which a figure is available. Consumption reached its peak in Ohio in the year 1916, when it was 169,480,011 M cu. ft., declining to 114,720,000 M cu. ft. in 1939. The production and consumption of natural gas in Ohio for the past five years are shown in Table 5.

Table 2.—*Completions in Ohio during Past Five Years*

Year	Number of Wells Drilled during Year			
	Oil	Gas	Dry	Total
1936	263	570	324	1,157
1937	317	503	451	1,271
1938	189	433	288	910
1939	170	501	349	1,020
1940	327	491	410	1,228
Total	1,266	2,498	1,822	5,586

Table 6 shows the number of oil wells and the number of gas wells completed by sands during 1940, with the average initial production per well for each sand.

Table 7 shows the total number of wells drilled—oil, gas and dry—by sands.

Development during 1940

Sub-Trenton.—For several years, considerable interest has been shown in a horizon lying some 500 to 700 ft. below the top of the Trenton, known to the driller in western Ohio as the "green sand," and in eastern Ohio as the St. Peter. In 1939, ten "green sand" tests were drilled, all in western Ohio and all dry. In 1940, eight wells were drilled to this horizon, one of which was a small oil well (one barrel) in Allen County. Of the remaining seven—all of which were dry—one in Franklin County, in central Ohio, was drilled to a depth of 2903 ft. Another was in Medina

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County, in northern Ohio, reaching a depth of 5071 ft. The others were drilled in Clinton, Greene, Putnam, Union, and Allen Counties.

TABLE 3.—*Annual Oil Production during Past Five Years*

Year	Production, Bbl.	Number of Oil Wells	Average per Well, Bbl.
1936	3,791,000	30,150	126
1937	3,654,000	28,122	130
1938	3,358,000	26,880	125
1939	3,144,000	25,680	122
1940	3,052,000	25,500	120

Trenton.—The Trenton is the producing formation of the old Lima-Findlay area in northwestern Ohio, and has been predominantly an oil-bearing formation. For the past few years the number of Trenton completions has been diminishing, there being a total of 75 Trenton completions in 1937; 34 in 1938; 28 in 1939, and 18 in 1940. All of those drilled in 1940 were in northwestern Ohio, of which eight were small oil wells, three were gas wells and seven were dry.

TABLE 4.—*Prices of Crude Oil in Ohio during* 1940

Date of Change	Pennsylvania	Corning	Lima	Cleveland	Lodi
January 1	$2.30	$1.12[a]	$0.90[a]	$1.00[a]	$0.95[a]
March 1					1.00
May 22	2.05				
June 21	1.80				
July 12	1.55				
August 28	1.40				
November 12	1.55				
December 17	1.70				

[a] No change from end of preceding year.

Clinton.—The completions in the Clinton sand in 1940 exceeded those of 1939 by about 34 per cent. The most noteworthy oil extension in the Clinton sand during the year under review was in Clayton township, Perry County. This pool was opened in 1936, but the greatest development occurred in 1940. The Clinton lies at a depth varying from 3300 to 3400 ft. The outstanding oil well for 1940 was completed in sec. 16, Clayton township, having a reported initial production of 160 bbl. per day from a depth of 3289 feet.

The greatest Clinton gas activity continued to be the pool in Licking County,

TABLE 5.—*Natural Gas in Ohio during Five-year Period*
THOUSANDS CUBIC FEET

Year	Annual Production	Annual Consumption
1935	49,592,000	105,896,000
1936	46,994,000	121,381,000
1937	42,783,000	125,133,000
1938	35,257,000	108,013,000
1939	36,469,000	114,720,000

northeast of the city of Newark. The discovery well was drilled in December 1938 and the extent of the producing area was fairly well determined by 1939. In Licking County, 125 wells (including dry holes) were drilled in 1939. In 1940 the total number of completions for the county was 159, of which 117 were Clinton tests.

TABLE 6.—*Number of Producing Wells Drilled during* 1940, *and Average Initial Production per Well*

Sand	Oil Wells		Gas Wells	
	Number of Wells	Average Initial per Well, Bbl.	Number of Wells	Average Initial per Well, M Cu. Ft.
Shallow	75	5.5	92	325.2
Berea	184	7.8	125	104.8
Ohio Shale	0		18	83.2
Oriskany	0		3	134.0
Newburg	2	20.0	21	977.0
Clinton	57	44.4	229	966.7
Trenton	8	11.8	3	201.0
Sub-Trenton	1	1.0	0	
Total	327	13.7	491	581.9

The largest gas well drilled in Ohio in 1940 was in sec. 5, Butler township, Knox County; it had an initial open flow of 12,000,000 cu. ft. and an initial rock pressure of 935 lb. The production was from the Clinton sand, at a depth of 2792 ft. Production was first discovered in this township several years ago. Another large gas well was completed in sec. 4, Wayne township, Muskingum County, producing from the Clinton at 3800 ft. and having an initial

open flow of 9,220,000 cu. ft. and an initial rock pressure of 518 lb. Two large Clinton gas wells were drilled in secs. 15 and 16, Brush Creek township, Muskingum County. The larger, in sec. 16, had an initial open flow of 6,520,000 cu. ft. and an initial rock pressure of 1050 lb. The well in sec. 15 had an initial open flow of 5,220,000 cu. ft. and an initial rock pressure of 1150 lb. The depth of the wells was approximately 4200 feet.

TABLE 7.—*Wells Completed in Ohio in 1940, by Sands*

Sand	Oil Wells	Gas Wells	Dry Holes	Total
Shallow	75	92	93	260
Berea	184	125	153	462
Ohio Shale	0	18	2	20
Oriskany	0	3	2	5
Newburg	2	21	5	28
Clinton	57	229	141	427
Trenton	8	3	7	18
Sub-Trenton	1	0	7	8
Total	327	491	410	1,228

Deep Wells.—The deepest well drilled during 1940 was in sec. 23, Center township, Noble County, finding the Clinton sand (dry) at a depth of 5620 to 5689 ft., and reaching a total depth of 5800 ft. Although it was not completed until 1941, a deeper well was drilled to the Clinton in sec. 19, Smith township, Belmont County. This test, also dry, went to a depth of 7887 feet.

OTHER DEVELOPMENT

Late in 1939, a growing interest in basin geology spread from Illinois to the area east of the Cincinnati arch in Ohio. Several of the larger oil companies have done considerable geophysical work in eastern and northeastern Ohio. Although at the present time the few wells reported as located by geophysical investigation have not been successful, the method should not be condemned until more is known as to the peculiarities of reflection and velocities affecting the method in Ohio.

During the year 1939, the water-flooding of oil sands was made legal in Ohio. Most of this type of secondary recovery has been done in Chatham township, Medina County. Because the undertaking is relatively recent, a report on the method cannot be included here.

TABLE 8.—*Completions in Ohio in 1940, by Counties*

County	Oil Wells	Gas Wells	Dry Holes	Total
Allen	1		1	2
Ashland	4	5	6	15
Ashtabula			1	1
Athens	13	57	35	105
Auglaize			1	1
Belmont		2	1	3
Carroll	1		2	3
Clinton			1	1
Columbiana			1	1
Coshocton	8	3	4	15
Cuyahoga	1	8	3	12
Fairfield	1	10	12	23
Franklin			1	1
Gallia		7	1	8
Geauga			1	1
Greene			1	1
Guernsey	5	22	15	42
Hancock			1	1
Harrison	1	2		3
Henry	2			2
Hocking	4		5	9
Holmes		16	11	27
Jackson		5		5
Jefferson	6		5	11
Knox	5	25	16	46
Lake			1	1
Lawrence		11	2	13
Licking	30	90	39	159
Lorain	13	15	24	52
Mahoning			4	4
Medina	121	16	49	186
Meigs	1	19	10	30
Monroe	14	19	24	57
Morgan	6	10	15	31
Muskingum	4	27	10	41
Noble	21	30	24	75
Perry	36	15	15	66
Putnam	1		2	3
Richland			1	1
Seneca	1	1	2	4
Stark	1	17	8	26
Summit		6	3	9
Tuscarawas		17	12	29
Union			1	1
Van Wert	3	3		6
Vinton		2	1	3
Washington	22	29	26	77
Wayne		2	9	11
Williams			1	1
Wood			1	1
Wyandot	1		1	2
Total	327	491	410	1,228

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Oil and Gas Development in Oklahoma in 1940

By Thomas Brownfield*

Development and production activity in Oklahoma during the year 1940 was of routine nature. Production, according to the Corporation Commission's figures, averaged 409,100 bbl. daily as compared with 421,000 bbl. for the year 1939. Discoveries were of minor importance except for the Cumberland pool in Marshall and Bryan Counties, in the southern part of the state. Maintenance of a relatively stable producing rate is attributable to the drilling of new wells and the recompletion of many old wells in the previously established producing areas.

During the year 1785 new wells were drilled, a decline of approximately 10 per cent as compared with the previous year. Of the wells drilled, 962 were oil wells with a combined initial production of 241,000 bbl. daily, 172 were gas wells having aggregate capacities of 1205 million cu. ft., and 651 were dry holes. Wildcat activity increased 20 per cent over 1939 and 227 such wells were completed during the year; that is, 43 oil wells, 16 gas wells, and 168 dry holes.

In addition to the new work completed, 603 wells were recorded as having been drilled deeper or plugged back to test new horizons; included were 334 producing wells with total initial production of 65,000 bbl. daily, 37 gas wells with initial aggregating 305 million cu. ft., and 232 abandonments.

Footage drilled amounted to 4,730,000 ft., an average of 2650 ft. per well as compared with an average depth of 2600 ft. recorded the previous year.

The principal new pools discovered as a result of the exploratory drilling were Cumberland; East Cromwell, in Okfuskee County, and Prague, in Lincoln County. At the end of the year Cumberland had 13 completed wells, which averaged 700 bbl. initial through tubing from the Simpson Bromide formation (Ordovician) at 4750 ft. East Cromwell had 10 wells with average initial of 435 bbl. in the Cromwell sand (Pennsylvanian) at 3460 ft. Prague had 11 wells with an initial average of 220 bbl. from the Senora sand (Pennsylvanian) at 3260 ft.

There were notable extensions to the Dill pool, Okfuskee County, and to the Hewitt pool, Carter County. At the end of the year, 19 producing wells had been drilled in the former, with initials averaging 1000 bbl., and 63 wells averaging 150 bbl. daily in the latter.

There were no notable changes in the policy of State conservation authorities with respect to proration. The Bureau of Mines recommendations for the year averaged 413,000 bbl. daily; the State authorities fixed allowables at an average of 406,000 bbl. daily, while, as noted above, production averaged 409,100 barrels.

The most important development in the older areas occurred in the following pools:

Billings.—Seven oil wells with an average initial production of 2500 bbl. and two dry holes were completed during the year. Production from the Simpson horizon averaged 6025 bbl. daily as compared with 5950 the previous year. Production from this field has been almost steady since reaching its peak early in 1937. The major portion of the pool is efficiently operated as

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* Carter Oil Co., Tulsa, Okla.

TABLE 1.—*Oil Production in Oklahoma*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	Number of Oil and/or Gas Wells			Oil-production Methods, End of 1940	
									During 1940	End of 1940	Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	During 1940	Completed to End of 1940	Completed	Producing Oil[c]	Flowing	Artificial Lift
	CENTRAL OKLAHOMA											
1	Avery, *Lincoln*	1939	120		3,291	3,291		4	3	4		4
2	Chandler, *Lincoln*	1924	1,255		11,658,132	319,152				50		50
3	Davenport, *Lincoln*	1924	2,335		11,807,058	165,798		222		117		117
4	Davenport, West, *Lincoln*	1940	40		5,344	5,344		2	2	2	*y*	*y*
5	Gessman, *Lincoln*	1934	160		363,105	23,424				10		10
6	Hoyt, *Lincoln*	1935	265		1,251,499	80,886		14		10		10
7	Kendrick, *Lincoln*	1940	20		24,402	24,402		1		1		1
8	Laffoon, *Lincoln*	1932	470		1,675,367	248,880		19	9	11		11
9	Lincreek, *Lincoln*	1932	275		215,912	17,934				9		9
10	Payson, *Lincoln*	1940	20		2,005	2,005		1	1	1	*y*	*y*
11	Peck, *Lincoln*	1926	160		394,919	53,436				3		3
12	Perkins, *Lincoln*	1940	60		105,982	105,982			1	3	*y*	*y*
13	Sac & Fox, *Lincoln*	1924–37	*y*		2,678,747	703,452			6	140	*y*	*y*
14	Skellyville, *Lincoln*	1925	630		1,741,115	35,136			1	13		13
15	Sporn, *Lincoln*	1936	200		582,217	78,690		10		6		6
16	Stroud, *Lincoln*	1923	590		8,761,456	134,688		69		29		29
17	North Wellston, *Lincoln*	1936	480		1,299,354	120,780				22		22
18	Wilzetta, *Lincoln*	1934	80		951,608	179,340		14	1	11		11
19	Wilzetta, South, *Lincoln*	1936	220		140,593	20,496				4		4
20	Miscellaneous, *Lincoln*				y^1	15,006				4	*y*	*y*
21	Cleveland, *Pawnee*	1904	4,255		39,990,515	155,550				262		262
22	Greenup, *Pawnee*	1926			y^1	0		Abandoned				
23	Hallett, *Pawnee*	1922	1,665		y^1	21,228				44		44
24	Jennings, *Pawnee*	1916	1,375		3,892,297	96,990				80		80
25	Keystone, *Pawnee*	1919	5,565		2,357,729	150,792			2	228		228
26	Lauderdale, *Pawnee*	1915	4,300		13,132,190	293,532				198		198
27	Maramec, *Pawnee*	1920	1,990		2,786,422	157,380				93		93
28	Masham, *Pawnee*	1924	290		y^1	8,052				5		5
29	Ralston, *Pawnee*	1924	205		y^1	5,124				2		2
30	Skedee, *Pawnee*	1926	160		y^1	8,052				4		4
31	Terlton, *Pawnee*	1912	980		871,216	20,496				14		14
32	Terlton, North, *Pawnee*	1917	2,010		3,092,672	79,056				76		76
33	Watchorn, *Pawnee*	1922	530		7,387,620	139,812			2	17		17
34	Miscellaneous, *Pawnee*	1918	280		y^1	12,810				7	*y*	*y*
35	Broyles, *Payne*	1918–39	170		x^1	45,750				7		7
36	Broyles, East, *Payne*	1940	60		30,361	30,361				3		3
37	Coyle, *Payne*	1938	988		1,061,815	651,846		33	9	33	*y*	*y*
38	Garr, *Payne*	1920	1,135		2,335,810	139,080				34		34
39	Ingalls, *Payne*	1914	1,110		5,982,719	130,662				35		35
40	March, *Payne*	1922	1,410		y^1	36,234				25		25
41	March, North, *Payne*	1926	155		y^1	28,182				8		8
42	Mehan, *Payne*	Prior to 1925	670		y^1	4,758				3		3
43	New Cushing, *Payne*	1916	185		x^1	1,830				2		2
44	Norfolk, *Payne*	1918	785		y^1	26,718				13		13
45	Norfolk, West, *Payne*	1929	390		y^1	87,474				23		23
46	Orlando, *Payne*	1929	210		941,302	42,456				1		1
47	Ramsey, *Payne*	1938	690		3,393,219	1,373,598		38	1	38	*y*	*y*
48	Ripley, *Payne*	1923	375		y^1	19,764				5		5
49	Ripley, North, *Payne*	1923	165		353,591	27,816				2		2

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Individual pool figures not available. Aggregate of all pools followed by superior figure 1 carried in one amount at end of the district.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.		Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
	Initial	Repressuring Operation[d]	Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1			y	Prue	Pen								
2			38	Various	Pen, Ord	S, L	Por	3,250	5,020		A		
3			43	Various	Pen	S	Por	2,600	3,580	50	ML		
4			46	Prue	Pen								
5			44	Cleveland	Pen	S	Por	y	y		M		
6			40	1st Wilcox	Ord	S	Por	y	5,100	y			
7			48	Prue	Pen								
8			21	Wilcox	Ord	S	Por	4,190	4,275		A	Wilcox	
9			46	Wilcox	Ord	S	Por	y	y				
10			y	Lower Skinner	Pen								
11			23	2nd Wilcox	Ord								
12			46	Hunton	Sil								
13			46	Prue	Pen	S							
14			41	Various	Pen, Sil, Cam-Ord	S, L							
15			46	Simpson	Ord	S		4,500	4,600	y			
16			41	Various	Pen, Ord	S	y	4,240	4,290	50		Wilcox	4,520
17			40	Wilcox	Ord	S							
18			40	Hunton, Viola	Sil-Dev, Ord								
19			40	Hunton, Viola	Sil-Dev, Ord								
20			y	Prue, Wilcox	Pen, Ord	S							
21			36	Various	Pen, Cam-Ord	S, L	Por	1,300	2,400				
22			y										
23			38	Various	Pen, Ord								
24			38	Various	Pen, Mis, Ord	S, L	y	y	y				
25			38	Various	Pen, Mis, Ord	S, L		1,100	1,970				
26			37	Various	Pen, Cam-Ord	S, L		1,185	3,000				
27			38	Various	Pen			2,400	3,200				
28			39	Various	Pen, Mis, Ord	S, L							
29			39	Various	Pen, Ord								
30			40	Bartlesville, Burgess, Skinner	Pen	S							
31			38	Various	Pen, Ord								
32			38	Various	Pen, Ord								
33			41	Various	Pen, Mis, Ord	S, L	Por			y	y		
34			37	Bartlesville, Wilcox	Pen, Ord	S							
35			40	Bartlesville, Viola, Wilcox	Pen, Ord	S, L							
36			36										
37			46	Wilcox, Hunton	Ord, Sil	S, L	y	y	y	y			
38			38	Various	Pen, Mis, Ord	S, L							
39			36	Various	Pen, Mis, Ord	S, L		3,115	3,760				
40			38	Various	Pen, Ord								
41			43	Wilcox	Ord	S							
42			42	Various	Pen, Mis, Sil-Dev, Ord								
43			38	Various	Pen, Ord								
44			38	Bartlesville, Wilcox	Pen, Ord	S							
45			38	Bartlesville, Wilcox	Pen, Ord	S							
46			41	Misener	Mis	S							
47			43	1st Wilcox	Ord	S		4,768	4,795	27			
48			43	Various	Pen, Ord	S, L							
49			43	Wilcox	Ord	S	Por	y	y	y	y		

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[e]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
50	Stillwater, *Payne*	1935	130		507,890	13,176		6		3		3
51	Stillwater, West, *Payne*	1940	40		53,619	53,619		2	1	2		2
52	Yale-Quay, *Payne*	1914	4,095		21,555,827	538,386				172		172
53	Miscellaneous, *Payne*	1926	160		y[1]	9,516				4		4
54	Aggregate for district of pools marked[1]				7,855,955					1,893		
55	Total Central Oklahoma				161,244,875	6,748,222						
	EAST CENTRAL OKLAHOMA											
56	Hoffman, *McIntosh*	1917	300		x[1]	2,562				7		7
57	Beland, *Muskogee*	1906	390		x[1]	18,666				16		16
58	Boyle, *Muskogee*	1927	230		y[1]	22,692				15		15
59	Boynton, *Muskogee*	1914	2,740		x[1]	19,398				41		41
60	Butler, *Muskogee*	1918	1,500		x[1]	34,404				67		67
61	Cole, *Muskogee*	1914	780		x[1]	7,686				17		17
62	Council Hill, *Muskogee*	1919	335		x[1]	40,992				26		26
63	Haskell, *Muskogee*	1909	1,750		x[1]	36,234				81		81
64	Jolly-Patton, *Muskogee*	1920	260		y[1]	365				20[2]		20
65	Link, *Muskogee*	1909	715		x[1]	47,214				32		32
66	Muskogee, *Muskogee*	1904	3,760		x[1]	54,168				148		148
67	Muskogee, North, *Muskogee*	1906	290		x[1]	365				25[2]		25
68	Robinson, *Muskogee*	1915	280		x[1]	None				2		2
69	Sheppard, *Muskogee*	1917	140		x[1]	3,660				1		1
70	Sommerville, *Muskogee*	1926			y[1]	Abandoned						
71	Transcontinental, *Muskogee*	1918	215		x[1]	3,294				8		8
72	Yahola, *Muskogee*	1914	680		x[1]	4,026				19		19
73	Miscellaneous, *Muskogee*				x[1]	8,784				17		17
74	Baltimore, North, *Okfuskee*	1922	525		y[1]	2,928				3		3
75	Bearden, *Okfuskee*	1924			y[1]	Abandoned						
76	Beidleman, *Okfuskee*	1930	100		255,708	12,810				6		6
77	Blakely, *Okfuskee*	1924	110		831,887	11,712				4		4
78	Carey, *Okfuskee*	1923	485		1,074,007	31,476				11		11
79	Clearview, *Okfuskee*	1927	240		y[1]	30,744				10		10
80	Deaner, *Okfuskee*	1920	1,460		y[1]	108,336				90		90
81	Fields, *Okfuskee*	1918	460		x[1]	15,738				17		17
82	Gregory, *Okfuskee*	1922	160		y[1]	22,326				11		11
83	Gypsy Hill, *Okfuskee*	1910	1,603		x[1]	24,522				20		20
84	Haydenville, *Okfuskee*	1939	240		50,948	20,496				4		4
85	Josey, *Okfuskee*	1923	525	10	y[1]	68,076				26		26
86	Keaton, *Okfuskee*	1919	210		x[1]	None				2		2
87	Lyons-Quinn, *Okfuskee*	1921	1,645		y[1]	49,776				24		24
88	Mason, *Okfuskee*	1940	20		3,730	3,730		1	1	1	y	
89	Micawber, *Okfuskee*	1923	160		y[1]	4,758				1		1
90	Morgan, *Okfuskee*	1923	340		y[1]	3,660				2		2
91	Okemah, *Okfuskee*	1921	820		y[1]	136,884			8	52		52
92	Okemah, East, *Okfuskee*	1940	50		53,614	53,614		5	5	5	y	y
93	Okemah, North, *Okfuskee*	1940	20		12,146	12,146		1	1	1	y	
94	Okfuskee, *Okfuskee*	1938	60		96,134	21,960				5		5
95	Paden, *Okfuskee*	1914	80		x[1]	8,784				3		3
96	Sheldon, *Okfuskee*	1916	900		x[1]	43,554				20		20
97	Weleetka, *Okfuskee*	1913	1,815		x[1]	215,940			13	72		72
98	Weleetka, South, *Okfuskee*	1937			54,952	4,026				3		3
99	Weleetka, West, *Okfuskee*	1926	140		471,525	248,880			13	12		12
100	Miscellaneous, *Okfuskee*	1927	160		x[1]	17,202				3	y	
101	Aztec, *Okmulgee*	1917	2,140		x[1]	27,816				69		69
102	Bald Hill, *Okmulgee*	1908	25,095		x[1]	441,762				827		827
103	Beets—Rapp, *Okmulgee*	1920			y[1]	None				Abd		

[2] No production last 10 months of 1940.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb per Sq. In.	Repressuring Operation[d]	Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
	Initial		Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
50			40	Wilcox	Ord	S	Por	4,300	4,306	6	A	Wilcox	4,306
51			41	Hunton	Sil								
52			38	Bartlesville, Oswego, Wilcox	Pen, Ord	S, L		2,670	3,580				
53			y	1st and 2nd Wilcox	Ord								
54													
55													
56			35	Wilcox	Ord	S							
57			35	1st and 2nd Dutcher	Pen	S							
58			38	Dutcher	Pen	S							
59			35	Mississippi	Mis	L							
60			32	Unidentified sand									
61			35	Unidentified sand									
62			38	Various	Pen								
63			34	Tucker	Pen								
64			43	Muskogee, Timber-Ridge									
65			36	Dutcher, Booch	Pen								
66			38	Unidentified sand, Wilcox	Ord	S		1,052	1,790		F		
67			35	Wilcox	Ord	S							
68			39	Muskogee									
69			39	Unidentified sand									
70			y										
71			39	Booch	Pen	S							
72			39	Booch, Boynton	Pen								
73			38	Leidecher, Dutcher, Wilcox	Pen, Ord								
74			38	Dutcher, 1st and 2nd Wilcox	Pen, Ord								
75			y										
76			38	Wilcox	Ord	S							
77			39	Unidentified sand									
78			32	Various	Pen								
79			38	Wilcox	Ord	S							
80			38	Deaner, Lyons, Wilcox	Pen, Ord	S		2,800	3,650				
81			43	Deaner, Wilcox	Pen, Ord	S							
82			39	Various	Pen, Ord								
83			33	Youngtown, Dutcher, Wilcox	Pen, Ord	S		2,430	3,290				
84			36	Dutcher, Wilcox	Pen, Ord	S							
85			40	Wilcox	Ord	S		3,600	3,650	50	D	Wilcox	3,700
86			39	Dutcher, Quin	Pen								
87			39	Lyons	Pen								
88			61	Hunton	Sil								
89			36	Wheeler, Dutcher	Pen								
90			37	Dutcher	Pen								
91			30	Gilcrease, Cromwell	Pen								
92			36	Lower Cromwell	Pen								
93			42	Hunton	Sil								
94			39	Wilcox, Dutcher	Ord, Pen								
95			36	Prue	Pen	S							
96			42	Wilcox	Ord								
97			39	Gilcrease	Pen	S		2,530	2,660	30			
98			39	L. Gilcrease	Pen	S							
99			36	Booch	Pen	S							
100			36	Various	Pen, Ord								
101			38	Booch, Wilcox	Pen, Ord	S							
102			30	Glenn	Pen	S		750	2,250				
103			y										

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
104	Beggs, North, *Okmulgee*	1909			x^1	31,476				40		40
105	Beggs, South, *Okmulgee*	1911	4,455		x^1	83,814				57		57
106	Brinton, *Okmulgee*	1914	545		x^1	8,418				17		17
107	Coalton, *Okmulgee*	1907	2,040		x^1	28,182				88		88
108	Edna, East, *Okmulgee*	1919	150		x^1	2,562				2		2
109	Eram, *Okmulgee*	1921	600		y^1	5,124				15		15
110	Hamilton Switch, *Okmulgee*	1909	2,570		x^1	34,770				82		82
111	Hector, *Okmulgee*	1914	645		x^1	1,464				11		11
112	Henryetta, *Okmulgee*	1910	785		x^1	11,712				47		47
113	Montezuma, *Okmulgee*	1918	220		x^1	5,490				4		4
114	Morris, *Okmulgee*	1907	7,300		x^1	141,642				271		271
115	Natura District, *Okmulgee*	1914	1,750		x^1	17,934				42		42
116	Nuyaka, South, *Okmulgee*	1937	105		423,942	57,828				7		7
117	Oklahoma Central, *Okmulgee*	1921	545		y^1	24,156				9		9
118	Okmulgee District, *Okmulgee*	1906	5,020		x^1	64,050				155		155
119	Phillipsville, *Okmulgee*	1920	580		y^1	11,346				8		8
120	Pine, *Okmulgee*	1915	815		x^1	6,954				26		26
121	Pollyanna, *Okmulgee*	1921	3,975		y^1	138,348				234		234
122	Schulter, *Okmulgee*	1907	455		x^1	6,954				15		15
123	Simmons-Black, *Okmulgee*	1920	455		y^1	51,972				13		13
124	Spencer, *Okmulgee*	1917	790		x^1	12,444				33		33
125	Summers, *Okmulgee*	1914	290		x^1	3,294				14		14
126	Tiger Flats, *Okmulgee*	1928	1,045		y^1	1,830				6		6
127	Youngstown, *Okmulgee*	1915	2,235		x^1	41,724				48		48
128	Miscellaneous, *Okmulgee*	1920	605		x^1	24,888				15		15
129	Airport, *Tulsa*	1937	330		135,766	6,954				54		54
130	Alsuma, *Tulsa*	1916	850		x^1	4,392				8		8
131	Bird Creek, *Tulsa*	1906	17,910		x^1	455,670				1,815		1,815
132	Bixby, *Tulsa*	1916	1,860		x^1	65,880				79		79
133	Broken Arrow District, *Tulsa*	1901	3,665		x^1	38,064				84		84
134	Bruner Vern *Tulsa*	1923			y^1	45,384				56		56
135	Collinsville, *Tulsa*	1916			x^1	4,392				12		12
136	Dawson, *Tulsa*	1906	765		x^1	13,176				63		63
137	Fisher, *Tulsa*	1918	685		x^1	5,490				7		7
138	Jenks, *Tulsa*	1901	6,885		x^1	94,062			1	352		352
139	Leonard, *Tulsa*	1916	1,000		x^1	20,496				36		36
140	Owasso, *Tulsa*	1913	360		x^1	8,784				24		24
141	Perryman, *Tulsa*	1924	345		y^1	1,830				11		11
142	Red Fork, *Tulsa*	1901	4,390		x^1	27,450				89		89
143	Sand Springs, *Tulsa*	1916	625		x^1	46,116				49		49
144	Tulsa, *Tulsa*	1901	910		x^1	1,098				7		7
145	Turkey Mountain, *Tulsa*	1922	1,115		y^1	22,326				49		49
146	Turley, *Tulsa*	1914	3,715		x^1	133,590				486		486

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.	Repressuring Operation[d]	Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
	Initial		Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
104			38	Youngstown, Wilcox	Pen, Ord								
105			37	Various	Pen, Mis, Ord								
106			37	Wilcox	Ord	S							
107			30	Booch, Wilcox	Pen, Ord	S		1,300	2,835				
108			30	Unidentified sand									
109			40	Wilcox	Ord	S							
110			29	Dutcher, Glenn, Wilcox	Pen, Ord	S		1,385	2,700				
111			37	Various	Pen, Mis, Ord	S, L							
112			38	Various	Pen, Sil-Dev, Cam-Ord	S, L							
113			38	Unidentified sand									
114			36	Various	Pen, Mis, Ord	S, L		1,600	2,450				
115			30	Various	Pen, Mis, Ord								
116			43	Wilcox	Ord	S							
117			32	Wilcox	Ord	S							
118			30	Various	Pen, Mis, Ord	S		1,240	2,750				
119			45	Wilcox	Ord	S							
120			35	Booch, Dutcher	Pen	S							
121			34	Various	Pen, Cam-Ord	S, L		1,365	2,285				
122			36	Glenn, Deaner, Wilcox	Pen, Ord								
123			36	Salt, Booch	Pen								
124			33	Various	Pen, Mis, Cam-Ord								
125			38	Dutcher	Pen	S							
126			37	Various	Pen, Ord								
127			31	Youngstown	Pen	S							
128			40	Dutcher, Booch, Wilcox	Pen, Ord	S							
129			38	Bartlesville	Pen	S							
130			35	Burgess	Pen	S							
131			31	Bartlesville, Wilcox	Pen, Ord	S		1,110	1,345				
132			32	Various	Pen, Ord	S, L							
133			37	Various	Pen, Mis, Cam-Ord	S, L		1,350	1,500				
134			37	Various	Pen-Cam-Ord								
135			33	Various	Pen, Mis	S, L							
136			36	Tucker, Bartlesville	Pen	S							
137			34	Oswego, Tyner, Arbuckle	Pen, Ord, Cam-Ord								
138			36	Various	Pen, Mis, Cam-Ord	S, L							
139			35	Various	Pen, Mis, Cam-Ord	S, L							
140			30	Various	Pen, Cam-Ord								
141			31	Unidentified sand									
142			34	Various	Pen, Cam-Ord			599	2,160				
143			37	Various	Pen, Cam-Ord								
144			34	Various	Pen, Mis, Ord								
145			35	Various	Pen, Cam-Ord								
146			32	Bartlesville, Burgess, Siliceous	Pen, Cam-Ord	S, L		1,260	1,945				

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	Number of Oil and/or Gas Wells			Oil-production Methods, End of 1940	
									During 1940	End of 1940	Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	During 1940	Completed to End of 1940	Completed	Producing Oil[c]	Flowing	Artificial Lift
147	Wicey, *Tulsa*	1915	2,200		x^1	57,462				119		119
148	Bilby, *Wagoner*	1918	150		x^1	23,058				15		15
149	Corine, *Wagoner*	1919	190		x^1	2,928				9		9
150	Coweta, *Wagoner*	1914	720		x^1	17,202				46		46
151	George, *Wagoner*	1918	270		x^1	28,914				31		31
152	Gillette, *Wagoner*	1924	65		y^1	1,830				9		9
153	Goble, *Wagoner*	1916	325		x^1	10,614				20		20
154	Johnson-Bailey, *Wagoner*	1920	80		y^1	1,098				3		3
155	McCracken, *Wagoner*	1920	90		y^1	2,928				18		18
156	Oak Grove, *Wagoner*	1920	145		y^1	1,098				2		2
157	O. K. Pool, *Wagoner*	1919	80		x^1	None				9		9
158	Oneta, *Wagoner*	1916	695		x^1	38,064				61		61
159	Seltzer, *Wagoner*	1924	65		y^1	2,562				17		17
160	Stone Bluff, *Wagoner*	1915	1,065		x^1	118,218				178		178
161	Striker, *Wagoner*	1917			x^1	Abandoned						
162	Wagoner, *Wagoner*	1914	460		x^1	3,294				42		42
163	Wagoner, South, *Wagoner*	1939	80		4,020	1,830				2		2
164	Webster, *Wagoner*	1917	60		x^1	4,026				11		11
165	Wright, *Wagoner*	y	80		y^1	None				3		3
166	Miscellaneous, *Wagoner*	1920	170		y^1	1,464				7		7
167	Aggregate for district of pools marked[1]				301,357,954					6,988		
168	Total East Central Oklahoma				304,826,333	4,078,286						
	EAST CENTRAL (CREEK COUNTY)											
169	Arno	1923	210		y^1	59,292				17		17
170	Arno, West	1940	20		15,326	15,326		1	1	1	y	
171	Big Pond	1924	470		y^1	118,950				36		36
172	Bowden	1906	3,495		x^1	129,198				236		236
173	Bristow	1916	5,225		x^1	361,974			27	141		141
174	Bristow, North	1922	1,700		y^1	124,806				104		104
175	Bristow, West	1922	565		y^1	50,142				20		20
176	Bruce	1926	515		y^1	39,894			1	39		39
177	Bruce, East	1939	100		y^1	10,614				8		8
178	Cushing	1912	24,940		356,114,270	3,339,750		3,668	3	1,819		1,819
179	Deep Fork	1920	3,345		y^1	127,734				160		160
180	Depew	1915	y		x^1	312,930				81		81
181	Donnelly	1924	730		y^1	129,564				38		38
182	Edna	1940	80		25,412	25,412				4		4
183	Glenn Pool	1905	15,970		219,274,070	1,244,034				1,780		1,780
184	Independent	1908	1,320		x^1	84,180			1	44		44
185	Iron Post	1917	925		x^1	31,476				59		59

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.	Repressuring Operation[d]	Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
	Initial		Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
147			37	Various	Pen, Mis, Ord	S, L		1,480	1,950				
148			35	Burgess, Dutcher	Pen								
149			39	Unidentified sand									
150			38	Various	Pen, Mis, Cam-Ord	S, L		700	1,280				
151			36	Dutcher	Pen	S							
152			38	Tyner	Ord								
153			37	Dutcher	Pen	S							
154			33	Unidentified sand									
155			43	Tyner	Ord								
156			33	Pitkin, Burgen	Pen, Ord								
157			36	Dutcher, Tyner, Burgen	Pen, Ord								
158			38	Mississippi, Dutcher, Tyner	Pen, Mis, Ord	SL		1,000	1,200				
159			37	Dutcher	Pen	S							
160			36	Various	Pen, Mis, Cam-Ord			1,840	2,275				
161			*y*										
162			35	Peru, Ordovician	Pen, Ord								
163			35	Pennsylvanian									
164			33	Burgen	Ord								
165			39	Pitkin	Pen	L							
166			32	Unidentified sand & lime									
167													
168													
169			36	Simpson-Wilcox	Ord								
170			40	Prue	Pen								
171			32	Jones, Glenn, Dutcher, Wilcox	Pen, Ord	S							
172			32	Taneha	Pen								
173			35	Layton, Ft. Scott, Oswego, Red Fork, Bartlesville, Dutcher, Miss., Wilcox	Pen, Mis, Ord	S, L		2,700	3,200				
174			35	Bartlesville, Layton, Ft. Scott, Oswego, Red Fork, Dutcher, Miss., Wilcox	Pen, Mis, Ord	SL							
175			35	Dutcher	Pen			3,152	3,155				
176			35	Dutcher, Layton, Ft. Scott, Oswego, Red Fork, Bartlesville, Miss., Wilcox	Pen, Mis, Ord								
177			*y*	Layton	Pen								
178			38	Numerous horizons	Pen, Ord	SL	Por			*x*	AF		
179			42	Prue, Layton, Dutcher, Peru	Pen								
180			32	Glenn, Dutcher, Wilcox	Pen, Ord	S		2,700	3,397				
181			37	Dutcher, 1st Wilcox	Pen, Ord								
182			36	Wilcox	Ord								
183			34	Glenn, Wilcox Arbuckle, etc.	Pen, Ord								
184			35	Taneha-Wilcox	Pen, Ord	S		2,100	2,550				
185			36	Wheeler, Prue Cleveland	Pen	S		2,420	2,475				

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
186	Kellyville	1934	3,600		y^1	240,462			0	204		204
187	Mannford (Deep-Shallow)	1922–1937	4,650		y^1	402,966				266		266
188	Mercer	1923	80		275,240	8,052				3		3
189	Mounds	1915	1,580		x^1	87,474				51		51
190	Newby	1929	80		y^1	6,588				6		6
191	Olean	1921	340		y^1	26,718				19		19
192	Olive	1914	2,235		x^1	191,784				205		205
193	Olive, South	1940	20		569	569		1	1	1		1
194	Pickett-Prairie	1916	1,820		x^1	14,274			1	60		60
195	Poor Farm	1920	340		y^1	25,986				13		13
196	Red Bank	1918	370		x^1	25,620				8		8
197	Sapulpa	1909	1,790		x^1	72,102			17	103		103
198	Sapulpa, South	1910	2,570		x^1	70,638				74		74
199	Slick	1913	6,585		x^1	420,534				174		174
200	Stroud, East	1940	40		16,017	16,017				2		2
201	Tibbens	1924	430		y^1	27,084				38		38
202	Tibbens, North	1940	20		6,203	6,203		1	1	1	y	
203	Tuskegee	1924	310		y^1	9,882			0	10		10
204	Tuskegee, East	1925	540		821,454	166,896				29		29
205	Walker	1923	390		y^1	57,462				29		29
206	Walker, West	1939			67,173	42,456				8		8
207	Wilcox	1919	1,375		x^1	180,804				58		58
208	Miscellaneous	1924	290		y^1	25,254				10	y	y
209	Aggregate for district of pools marked[1]				189,649,510							
210	Total East Central, Creek County				766,265,244	8,331,101				5,959		
	NORTHEASTERN											
211	Craig, Nowata, Rogers, and Washington Counties				350,230,873	6,276,900				15,581		15,581
	NORTHERN											
212	Barnes, *Garfield*	1918	185		x^1	8,784				10		10
213	Brown, *Garfield*	1930	85		407,186	20,496			1	4		4
214	Enid, *Garfield*	1940	20		10,861	10,861		1	1	1	y	
215	Garber, *Garfield*	1916	4,520		54,510,644	623,298		973	2	565		565
216	Garber, North, *Garfield*	1927	90		y^1	10,614				7		7
217	Hillsdale, *Garfield*	1938	70		79,903	10,980				1		1
218	Waukomis, *Garfield*	1938	30		34,924	5,856		1		1		1
219	Reed, *Garfield*	1926			58,365	2,928				1		1
220	Cardwell, *Grant*	1929	80		261,048	8,784				2		2
221	Deer Creek, *Grant*	1922	210		1,235,217	80,520				11		11
222	Lamont, *Grant*	1937	60		556,239	212,646		2		2		2
223	Webb, *Grant*	1926	120		203,273	8,784				3		3
224	Barkwell, *Kay*	1918	1,750		4,559,590	165,798				43		43
225	Bramar, *Kay*	1924	335		4,549,918	161,772			3	30		30

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In. Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
186			30	Peru	Pen	S							
187			35	Various	Pen, Ord	S, L		1,550	2,980				
188			41	Dutcher-Wilcox	Pen, Ord	S							
189			33	Red Fork, Glenn, Tucker, Dutcher, Wilcox	Pen, Ord	S		400	2,400				
190			34	Dutcher	Pen	S							
191			40	Layton, Peru, Skinner, Wheeler, Bartlesville	Pen								
192			36	Layton, Wheeler, Skinner, Bartlesville, etc.	Pen	S							
193			39	Prue	Pen								
194			35	Glenn, Taneha, Wilcox	Pen, Ord								
195			34	Various	Pen								
196			36	Various	Pen, Ord								
197			34	Various	Pen, Mis, Ord	S, L		1,000	2,290				
198			36	Taneha, Dutcher, Wilcox	Pen, Ord								
199			32	Various	Pen, Mis, Ord			2,340	3,088			Wilcox	3,140
200			39	2nd Wilcox	Pen, Ord								
201			34	Various									
202			36	Wilcox	Ord								
203			38	Various	Pen, Ord								
204			39	Various	Pen, Mis, Ord								
205			35	Various	Pen, Mis, Ord	S, L							
206			y	Bartlesville	Pen	S							
207			35	Various	Pen, Ord								
208			39	Bartlesville, Prue, Wilcox	Pen, Ord	S							
209													
210													
211			36										
212			41	Tonkawa, Layton	Pen								
213			43	Wilcox	Ord	S							
214			40	Mis. lime	Mis								
215			43	Various	Per, Pen, Ord	S, L	Por	1,100	4,200	y		y	y
216			44	Various	Pen, Ord								
217			44	1st and 2nd Wilcox	Ord	S		y	y			y	y
218			53	Marshall Zone		S	y	7,260	7,280	20		y	y
219			43	Wilcox	Ord	S							
220			44	Wilcox	Ord	S	Por	y	y	6	A	y	y
211			39	Various	Pen, Mis, Ord	S, L		2,900	4,175	y			
222			49	Wilcox	Ord	S	y	5,400	5,410	10		y	y
223			42	Various	Pen, Mis, Ord								
224			40	Various	Pen, Ord	S, L		1,600	3,440				
225			41	Various	Pen, Ord	S, L							

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	Number of Oil and/or Gas Wells			Oil-production Methods, End of 1940	
									During 1940	End of 1940	Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	During 1940	Completed to End of 1940	Completed	Producing Oil[c]	Flowing	Artificial Lift
226	Braman, North, *Kay*	1924	795		17,970,967	296,460				60		60
227	Braman, Southeast, *Kay*	1938	200		147,663	60,390				5		5
228	Dilworth, *Kay*	1917	2,355		5,119,054	150,426				76		76
229	Hubbard, *Kay*	1924	645		8,224,258	183,000				36		36
230	Mervine, *Kay*	1913	960		x^1	11,346				2		2
231	New Kirk, *Kay*	1919	250		x^1	22,326				6		6
232	Ponca City, *Kay*	1917	1,445		6,314,054	96,624[3]				40		40
233	Thomas, *Kay*	Prior to 1914	275		7,096,933	77,226				14		14
234	Tonkawa, *Kay*	1921	3,695		120,736,862	627,324		929		210		210
235	Tonkawa South, *Kay*	1921	295		x^1	None				Abandoned		
236	Vernon, *Kay*	1925	660		3,241,698	95,526				16		16
237	Miscellaneous, *Kay*				x^1	6,588				5	y	y
238	Crescent, *Logan*	1933	955		12,888,103	773,358		54		40	y	y
239	Hull, *Logan*	1934	80		218,863	15,372				2		2
240	Langston, *Logan*	1934	340		979,696	122,244			0	13	y	y
241	Langston, South, *Logan*	1935	130		42,361	7,686				1		1
242	Lovell, *Logan*	1928	220		2,616,752	36,600				8		8
243	Lovell, West, *Logan*	1936	50		95,176	2,196		2		Abandoned		
244	Lovell, South, *Logan*	1934			111,652	69,540			3	5		5
245	Marshall, *Logan*	1927	740		11,728,125	73,932				24		24
246	Meridian, *Logan*	1938	120		144,108	49,044		7		6		6
247	Seward, *Logan*	1936	40		63,367	10,248			0	1		1
248	Billings (deep sand), *Noble*	1935	1,060		9,009,446	2,204,418		79	7	78	y	y
249	Billings (shallow sand)	1917	590		6,182,833	9,150				7		7
250	Lucien, *Noble*	1932	4,170		26,389,833	2,740,242		128	2	123	y	y
251	Lucien, North, *Noble*	1936	430		822,085	229,482				12	y	y
252	Marathon, *Noble*	1935	80		136,243	8,052				3		3
253	Otoe, *Noble*	1930	40		75,440	4,026				1		1
254	Perry, *Noble*	1923	60		73,973	4,392				1		1
255	Polo, *Noble*	1934	510		3,771,246	387,228		37	0	31		31
256	Sams, *Noble*	1925	295		2,266,080	34,038				7		7
257	Aggregate of pools marked[1]				3,167,780					1,514		
258	Total Northern Oklahoma				316,101,819	9,740,605						
	OKLAHOMA CITY AREA											
259	Moore, *Cleveland*	1935	940		7,973,819	597,678		40	0	38		38
260	Noble, *Cleveland*	1938	40		28,672	Abandoned		1		Abandoned		
261	Norman, *Cleveland*	1939	40		6,253	732				1		1
262	Britton, *Oklahoma*	1935	1,245		2,280,616	210,450			2	29		29
263	Vanek (Britton South), *Oklahoma*	1938 1938	70		109,994	41,358		2		2	y	y
264	Edmond, *Oklahoma*	1930	1,440		16,812,772	1,487,058		104	0	84		84
265	Jones, *Oklahoma*	1939	60		39,890	36,966			2	3		3
266	Newalla, South, *Oklahoma*	1939	40		20,440	6,588				1	y	
267	Nicoma Park, *Oklahoma*	1929	80		338,352	10,248		2		2		2
268	Oklahoma City, *Oklahoma*	1928	14,100		524,913,045	35,720,136		1,504	30	1,008	y	y
269	Total Oklahoma City Area				552,523,853	38,111,214				1,168		
	OSAGE COUNTY											
270	Alemeda	1918	1,205		x^1	12,810				79		79
271	Atlantic	1924	1,330		y^1	314,028				91		91

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.		Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
								Depth, Avg. Ft.					
	Initial	Repressuring Operation[d]	Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
226			41	Various	Pen, Ord	S, L							
227			43	Wilcox	Ord	S	*y*	*y*	*y*	*y*		*y*	*y*
228			40	Blackwell	Pen					*y*	A		
229			39	Various	Pen, Ord		Por	*y*	*y*	*y*	AF	*y*	*y*
230			40	Various	Pen								
231			40	Burbank, Mississippian	Pen, Mis								
232			38	Various	Pen, Mis, Ord	S, L		1,500	3,900		A		
233			41	Various	Per, Pen, Ord	S, L	Por			*y*	*x*		
234			42	Various	Pen, Mis, Ord	SL	Por	2,660	4,075	*y*	*x*		
235			42	Endicott, Tonkawa, Wilcox	Pen, Ord								
236			40	Various	Pen, Mis, Ord	S, L				*y*	*x*		
237			39	Various									
238			42	Layton, 2nd Wilcox, Wilcox	Pen, Ord	S	23				AF		
239			40	Layton, Tonkawa, Wilcox	Pen, Ord	S	Por		4,800				
240			45	Wilcox	Ord	S	Por	5,100	5,145		A	Wilcox	5,19
241			45	Upper Simpson	Ord								
242			40	Tonkawa, Wilcox	Pen, Ord	S	*y*	*y*	*y*				
243			40	2nd Wilcox	Ord	S	Por	*y*		*y*	*y*		
244			40	Layton	Pen								
245	1,950		40	Tonkawa, L. Simpson, Wilcox	Pen, Ord	S	*y*	*y*	*y*	*y*			
246			48	Wilcox	Ord	S	*y*	5,200	5,220	20			
247			38	Simpson dolomite	Ord	D							
248	1,720		41	Wilcox	Ord	S	Por	4,250	*y*	*y*	A		
249			41	Various	Pen	SL	Por			50	A		
250			42	Various	Pen, Ord	SL	Por	*y*	5,200	*y*	*y*		
251			44	Wilcox	Ord	S	Por	*y*	*y*	*y*	*y*		
252	1,665		42	Wilcox	Ord	S	Por	*y*	*y*	34	A		
253			39	Layton	Pen	S	Por	3,284	3,314	30	*y*		
254			41	Reagan, Tonkawa	Pen, Ord								
255			41	Various	Pen, Ord	S	*y*	4,823	4,900	*y*	*y*		
256			42	Tonkawa	Pen	S		1,902	1,912	10			
257			35.98										
258				2nd Wilcox, U. Simpson	Ord	S, D	Por				A		
259			41	Dol. 2nd Wilcox	Ord								
260			39	2nd Wilcox	Ord	S		7,670	7,672	2			
261			38	U. Simpson	Ord	*y*	*y*	*y*	*y*	*y*			
262	2,000		45	Simpson, 2nd Wilcox	Ord	S, D, L	Por				AF		
263			35	2nd Wilcox	Ord	S		6,738	6,766	28			
264			39	Simpson, Wilcox	Ord		Por				AF	Arbuckle	7,000
265			35	Cleveland	Pen	S	*y*	4,796	4,808	12		2nd Wilcox	5,998
266			35	Hunton	Sil-Dev	L		6,004	6,095	91		2nd Wilcox	6,610
267			36	Trosper	Pen	S	Por	6,157	6,168	11	ML		
268			37	Various	Pen, Ord	SL	Por		6,700	*y*			
269													
270			33	Bartlesville, Burgess, Mississippian	Pen, Mis								
271			39	Burgess, Siliceous	Mis, Cam-Ord	S, L		2,500 2,750	2,525 2,765	25 15			

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	Number of Oil and/or Gas Wells			Oil-production Methods, End of 1940	
									During 1940	End of 1940	Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	During 1940	Completed to End of 1940	Completed	Producing Oil[c]	Flowing	Artificial Lift
272	Avant	1904	12,520		x^1	676,002				759		759
273	Avant, West	1905	3,555		x^1	79,788				174		174
274	Backins	1919	850		x^1	9,150				34		34
275	Bandwheel	1921	630		y^1	43,920				38		38
276	Barker	1932	240		y^1	48,678				11		11
277	Barnsdall	1916	3,620		x^1	69,174				203		203
278	Barnsdall, South	1921	1,125		y^1	28,914				87		87
279	Barnsdall, West	1922	1,665		y^1	132,126				97		97
280	Bartlesville	1904	16,335		x^1	17,202				81		81
281	Bighorse	1927	335		y^1	5,124				23		23
282	Birch Creek	1920	830		y^1	8,052				49		49
283	Boston	1904	770		x^1	120,414				39		39
284	Boston, North	1921	240		y^1	18,666				12		12
285	Bowring	1921	160		y^1	4,026				12		12
286	Branstetter	1928	420		y^1	32,208				25		25
287	Buell	1922	100		y^1	12,810				9		9
288	Bulldog	1920	465		y^1	50,874				32		32
289	Burbank (*Osage and Kay*)	1920	24,665		201,887,685	2,860,290		2,203		1,703		1,703
290	Burbank, South	Or. 1926 Ext. 1934	4,465		28,021,878	2,922,876		287		239	y	y
291	Candy Creek	1920	1,420		y^1	75,030				56		56
292	Canyon Creek	1923	160		y^1	64,416				5		5
293	Country Club	1923	515		y^1	27,450				31		31
294	Dalton	1926	205		y^1	3,660				3		3
295	Dewey	1904	4,920		x^1	21,594				108		108
296	Domes	1917	3,740		x^1	84,546				208		208
297	Edgewood	1921	285		y^1	7,686				16		16
298	Elgin, South	1917	1,985		x^1	20,130				119		119
299	Enfisco	1921	290		1,032,178	14,274				7		7
300	Fairfax	1925	220		y^1	42,822				16		16
301	Falls Dome	1920	380		y^1	21,960				22		22
302	Flat Rock	1906	7,485		x^1	290,238				596		596
303	Flesher	1919	320		x^1	9,150				5		5
304	Foraker	1920			y^1	Abandoned						
305	Forty-five	1916	1,795		x^1	32,208				110		110
306	Frankfort	1920	120		y^1	Abandoned						

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
272		RP	33	Bartlesville, Burgess	Pen	S		1,400 1,450	1,465 1,600				
273			32	Bartlesville, Burgess	Pen	S							
274			34	Bartlesville, Mississippian	Pen, Mis	SL							
275			34	Various	Pen, Mis	SL							
276			36	Various	Pen, Mis, Cam-Ord								
277			33	Peru, Bartlesville, Mississippian, Arbuckle	Pen, Mis, Cam	S, L		1,110 1,550	*y* 1,725	*y* 75			
278			33	Bartlesville, Burgess	Pen	S							
279			34	Bartlesville	Pen	S							
280			33	Various	Pen	L, S		650	1,265				
281			35	Bartlesville, Mississippian	Pen, Mis								
282			34	Bartlesville, Burgess, Mississippian	Pen, Mis	SL							
283			37	Various	Pen, Cam, Ord, Mis	SL		1,500	2,620				
284			36	Wilcox, Arbuckle	Cam, Ord								
285			34	Layton, Peru, Oswego, Mississippian	Pen, Mis	SL							
286			40	Bartlesville, Burgess, Mississippian	Pen, Mis	SL							
287			37	Various	Pen, Mis	SL							
288			34	Various	Pen, Mis	SL							
289		RP	38	Burbank, Layton, Wilcox	Pen, Ord	S		2,700	2,850	60	ML	Granite	4,240
290		PM	38	Burbank, Skinner	Pen	S			2,850				
291			33	Bartlesville, Burgess	Pen	S							
292			39	Bartlesville, Burgess	Pen	S							
293			33	Various	Pen, Ord								
294			38	Bartlesville, Burgess	Pen	S							
295			33	Various	Pen	L, S		650	1,265				
296			36	Stray, Bartlesville, Missisipian	Pen, Mis	SL, S, SL		1,570 1,680 1,880	1,124 1,780 1,925	67 100 45			
297			35	Bartlesville, Burgess, Mississippian	Pen, Mis	SL							
298			33	Ramsey, Pennsylvanian, Oswego	Pen								
299			36	Stray, Oswego, Mississippian	SL								
300			38	Burbank, Oswego, Wilcox	Ord, Pen	S	20-25			*y*	ML		
301			36	Oswego, Burgess, Bartlesville	Pen								
302		RP	34	Bartlesville, Burgess	Pen	S		1,110 1,345	1,205 1,365	95 20		Wilcox	1,667
303			35	Bartlesville, Mississippian	Pen-Mis								
304			33	Hominy, Arbuckle	Cam-Ord								
305			34	Oswego, Skinner, Bartlesville	Pen								
306			33	Pennsylvanian, Oswego, Mississippian	Pen, Mis	SL							

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
307	Gilliland	1919	770		*x*[1]	18,300				16		16
308	Happy Hollow	1919	540		*x*[1]	48,678				29		29
309	Hardy	1934	40		77,244	7,686				1		1
310	Hickory Creek	1914	2,220		*x*[1]	34,404				155		155
311	Hickory Creek, East	1939	340		108,836	84,546				15		15
312	Hominy	1916	415		*x*[1]	15,006				11		11
313	Hominy, East	1918	630		*x*[1]	17,568				23		23
314	Hominy, South	1940	40		2,477	2,477				2		22
315	Hominy Falls	1919	1,385		*x*[1]	31,476				54		54
316	Kasishke	1921	140		*y*[1]	11,346				17		17
317	Kaw	1922	180		155,034	59,292				7		7
318	Landon	1919	145		*x*[1]	2,928				9		9
319	Lee Dome	1926	80		*y*[1]	7,320				5		5
320	Madaline	1920	520		*y*[1]	29,280				37		37
321	Madaline, East	1923	400		*y*[1]	20,130				35		35
322	Manion	1927	460		816,571	30,744				37		37
323	Manion, North	1920	910		*y*[1]	54,168				59		59
324	Myers	1919	260		*x*[1]	5,124				7		7
325	Naval Reserve	1933	3,290		15,920,314	1,284,294		254		236		236
326	Nelagoney	1919			*x*[1]	Abandoned						
327	New England	1920	585		*y*[1]	40,260				27		27
328	Ochelata, North	1910	1,560		*x*[1]	61,122				89		89
329	Ohio-Osage	1932	195		*y*[1]	5,124				24		24
330	Okesa	1904	1,210		*x*[1]	6,588				22		22
331	Osage City	1904	*y*		*x*[1]	267,912				222		222
332	Osage City, East	1920	805		*y*[1]	86,376				64		64
333	Osage-Hominy	1917	1,625		*x*[1]	218,868				139		139
334	Page	1918	745		*x*[1]	38,430				32		32
335	Pawhuska	1919	505		*x*[1]	36,600				19		19
336	Pawhuska, West	1919	180		*x*[1]	4,392				7		7
337	Pearsonia	1919	180		*x*[1]	27,816				11		11
338	Penn Creek	1922	160		*y*[1]	11,712				3		3
339	Pershing	1918	5,595		*x*[1]	109,800				306		306
340	Pettit	1923	285		*y*[1]	30,012				20		20
341	Pioneer	1920	310		*y*[1]	20,862				24		24
342	Pond Creek	1913	1,295		*x*[1]	18,666				56		56
343	Prue	1926	475		*y*[1]	8,052				13		13
344	Quapaw	1914	3,645		*x*[1]	48,312				229		229

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In. Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
307			36	Various	Pen, Mis, Cam, Ord	SL							
308			36	Oswego, Burgess, Bartlesville	Pen								
309			39	Layton	Pen	S							
310			35	Oswego, Mississippian, Bartlesville	Pen, Mis	SL							
311			y	Wayside									
312			34	Various	Pen, Mis, Cam, Ord	SL		2,625	2,685	50	A	Arbuckle	3,206
313			34	Bartlesville, Mississippian, Hominy, Arbucle	Pen, Mis, Cam, Ord	S		2,160	2,210		A	Arbuckle	2,857
314			40	Oswego	Pen								
315			36	Various	Pen, Mis	SL							
316			40	Burbank	Pen	S							
317			y	Skinner, Prue	Pen								
318			35	Penn, Oswego, Bartlesville	Pen								
319			36	Oswego, Burgess, Bartlesville	Pen								
320			35	Oswego, Prue, Bartlesville	Pen								
321			35	Bartlesville	Pen	S							
322			38	Burgess, Layton, Oswego, Bartlesville	Pen								
323			38	Wilcox, Bartlesville	Pen ,Ord	S							
324			34	Layton, Burgess	Pen								
325			39	Burbank	Pen	S				y	y		
326			35										
327			34	Bartlesville, Burgess-Arbuckle	Pen, Cam, Ord								
328			34	Prue, Bartlesville	Pen	S							
329			37	Cleveland, Bartlesville	Pen	S							
330			34	Prue, Bartlesville, Mississippian	Pen, Mis	SL							
331			37	Burgess, Burbank, Arbuckle	Pen, Cam, Ord	SL							
332			37	Cleveland, Bartlesville	Pen	S		{ 1,620 { 2,250	1,645 2,280	25 } 30 }		Mississippi	2,431
333			37	Layton, Oswego, Bartlesville Burgess	Pen	SL		y	y	y			
334			33	Various	Pen, Cam, Ord	SL							
335			35	Bartlesville, Burgess, Burgen, Arbuckle	Pen, Cam, Ord	SL							
336			36	Bartlesville, Burgess, Burgen, Arbuckle	Pen, Cam, Ord	SL							
337			36	Burgess, Layton, Oswego, Mississippian	Pen, Mis	SL							
338			35	Bartlesville, Mississippian	Pen, Mis	SL							
339			35	Cleveland, Bartlesville	Pen	S		{ 1,385 { 2,033	1,400 2,063	15 } 30 }	D		
340			36	Various	Pen, Cam, Ord	SL		y	y	45	A	2nd Wilcox	
341			34	Various	Pen, Ord	SL							
342			33	Various	Pen, Mis	SL							
343			36	Prue, Bartlesville	Pen	S							
344			34	Bartlesville, Oswego, Skinner	Pen	S		1,720	1,780	60			

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940, Completed	Number of Oil and/or Gas Wells: End of 1940, Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
345	Ramona	1911	1,755		x[1]	72,102				81		81
346	Skiatook	1911	715		x[1]	18,666				30		30
347	Sunset	1919	295		x[1]	2,196				10		10
348	Tidal Osage	1918	1,975		x[1]	94,794				109		109
349	Turkey Creek	1917			x[1]	Abandoned						
350	Turkey Creek, West	1925	305		y[1]	2,196				38		38
351	White Tail	1919	205		x[1]	5,124				11		11
352	Wild Horse	1912	4,670		x[1]	281,454				414		414
353	Wild Horse, North	1919	360		x[1]	21,228				21		21
354	Wild Horse, South	1923	205		y[1]	8,418				11		11
355	Wild Horse, West	1940	20		1,643	1,643				1	y	
356	Woolaroc	1917	2,525		x[1]	54,534				160		160
357	Wynona	1917	3,475		x[1]	82,350				170		170
358	Miscellaneous	1934	1,840		y[1]	125,538				95	y	y
359	Aggregate for district of pools marked[1]				317,264,148					8,312		
360	Total Osage district				565,288,008	11,758,210	68					
	SEMINOLE AREA											
361	Adams, *Hughes*	1935	185		1,055,344	266,814		10		10		10
362	Alabama, *Hughes*	1923	640		y[1]	42,456				24		24
363	Buchner, *Hughes*	1924	140		y[1]	10,980				2		2
364	Calvin, *Hughes*	1938	80		58,602	9,882		3	1	3		3
365	Fish, *Hughes*	1934	1,280		15,803,710	1,147,776			10	131		131
366	Freame, *Hughes*	1938			21,203	5,856				2		2
367	Fuhrman, *Hughes*	1925	395		y[1]	13,542				11		11
368	Gilcrease, *Hughes*	1924			y[1]	3,660				2		2
369	Holdenville, North, *Hughes*	1926	80		30,673	2,196			1	1		1
370	Holdenville, West, *Hughes*	1916–30	1,340		4,908,342	249,246				117		117
371	Lamar, *Hughes*	1923	40		104,160	365						
372	Papoose, *Hughes*	1923	2,815		23,158,482	229,848		279		58		58
373	Spaulding, *Hughes*	1929	80		72,720	3,660				3		3
374	Wetumka, *Hughes*	1923	255		y[1]	15,372				4		4
375	Wetumka, East, *Hughes*	1938	80		40,874	14,640				1		1
376	Wetumka, South, *Hughes*	1926	100		y[1]	2,562				5		5
377	Yeager, *Hughes*	1925	345		1,958,485	31,476				7		7
378	Yeager, North, *Hughes*	1936	270		108,756	30,012			1	8		8
379	Miscellaneous, *Hughes*	1927	220		y[1]	12,078				7		7
380	Cromwell, North, *Okfuskee*	1938			203,060	143,472			6	10		10
381	Dill, *Okfuskee*	1931	1,060		2,898,760	649,284		59	22	54	y	y
382	Olympic, *Okfuskee*	1934	3,860		10,794,694	739,320		348		332		332
383	Asher, *Pottawatomie*	1929	430		3,581,018	21,228		69		8		8
384	Asher, West, *Pottawatomie*	1930	780		7,375,163	99,918				33		33
385	Avoca, *Pottawatomie*	1938	100		591,156	367,464		10	2	10		10
386	Earlsboro, West, *Pottawatomie*	1924 1929	1,345		2,063,771	121,512				24		24
387	Gray, *Pottawatomie*	1932	240		3,993,026	299,022		35	4	27		27
388	Grisso, *Pottawatomie*	1934	210		328,998	25,620				3		3
389	King, *Pottawatomie*	1939			105,804	29,280				3		3
390	Pace, *Pottawatomie*	1939			223,544	195,444			3	6		6

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In. — Initial	Repressuring Operation[d]	Character of Oil — Gravity A.P.I. at 60°F., Weighted Average	Producing Formation — Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. — Top Prod. Zone	Depth, Avg. Ft. — Bottoms Prod. Wells	Net Thickness Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940 — Name	Depth of Hole, Ft.
345			33	Big Lime, Bartlesville Burgess	Pen	SL							
346			34	Bartlesville, Burgess, Mississippian	Pen, Mis	SL							
347			36	Bartlesville, Hominy, Arbuckle	Pen, Ord	SL							
348			36	Burgess, Bartlesville	Per, Pen	S							
349			33										
350			33	Penn sand									
351			32	Stray, Bartlesville, Mississippian	Pen, Mis	SL							
352			35	Various	Pen, Ord	SL		3,550	4,260				
353			35	Various	Pen, Ord	SL							
354			35	Various	Pen								
355			38	Arbuckle	Cam, Ord								
356			34	Skinner, Bartlesville	Pen	S							
357			35	Various	Pen, Mis	SL		1,600	2,281				
358			y										
359													
360													
361	1,500			Misener	Mis	S	P			15	A	Wilcox	4,317
362			39	Various	Pen								
363			35	Booch, Cromwell	Pen	S		y	y	y			
364			36	Viola	Ord	L		y	y	y			
365			37	Various	Pen, Ord			y	y	y			
366			36	Cromwell	Pen	S		3,335	3,354	19			
367			37	Gilcrease-Cromwell	Pen	S		y	y	y			
368			39	Gilcrease	Pen	S		y	y	y			
369			40	Cromwell	Pen	S		3,418	3,437	19			
370			37	Various	Pen, Ord	S							
371			39										
372			36	Calvin, Cromwell, Gilcrease	Pen	S	Por			10	A	Wilcox	
373			35	Booch	Pen	S							
374			38	Various	Pen, Sil-Dev	S, L							
375			53	2nd Wilcox	Ord	S							
376			39	Gilcrease, Cromwell	Pen	S							
377			39	Various	Pen, Ord Sil-Dev	S, L							
378			37	Cromwell, Hunton 2nd Wilcox	Pen, Ord Sil-Dev	S, L							
379			y	Booch, Cromwell	Pen	S							
380			37	Cromwell, Booch	Pen	S							
381			40	Hunton, Cromwell, Senora	Pen, Sil-Dev	S, L	Por	Senora 1,685	Senora 1,785	Hunton 30 Senora y			
382			34	Cromwell-Senora	Pen	S	Por	3,433	3,475	y			
383			39	Wanette-Viola	Ord	S, L		y	y	y			
384			43	Wanette				3,450					
385			39	Viola, 2nd Wilcox	Ord	S, L		Viola 4,206	Viola 4,208	2			
386			38	Hunton	Sil-Dev	L		y	y	y			
387			40	Wanette, Hunton, Simpson	Sil-Dev, Ord			2,500	3,475	25	A	Wilcox	3,500
388			36	Hunton, Simpson	Sil-Dev, Ord	L		Hunton 4,030	Hunton 4,050			Wilcox	4,860
389			41	Viola and Hunton	Ord-Sil	L		4,374	4,416	42			
390			41	Hunton	Sil-Dev	L		4,281	4,306	25			

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
391	Maud, *Pottawatomie*	1928	1,980		11,861,181	202,764		155		57		57
392	Prague, *Pottawatomie*	1940			159,183	159,183		12	12	12	y	y
393	Romulus, *Pottawatomie*	1940			88,204	88,204				3	3	
394	Sacred Heart, *Pottawatomie*	1939	80		218,989	143,106			3	9		9
395	Shawnee, *Pottawatomie*	1934	520		2,365,048	723,216			19	54		54
396	Shawnee, East, *Pottawatomie*	1937	40		63,258	6,954		2		1		1
397	Shawnee, North, *Pottawatomie*	1937	80		143,109	87,474			2	3		3
398	St Louis, *Pottawatomie*	1927	19,825		147,980,937	9,453,780		1,176	40	890	y	y
399	Tecumseh, *Pottawatomie*	1937	40		118,486	27,084		1		1		1
400	Miscellaneous, *Pottawatomie*	1935	110		y[1]	3,660				3		3
401	Allen (Deep), *Seminole*	1927	3,000		49,842,144	1,918,206		466	13	309		309
402	Bethel, *Seminole*	1925	620		1,764,180	63,684				36		36
403	Bethel, North, *Seminole*	1936	455		3,101,851	691,374		30		28		28
404	Bowlegs, *Seminole*	1926	4,270		116,781,421	2,464,278		364		222		222
405	Carr City, *Seminole*	1927	1,885		30,020,722	840,336		121		84		84
406	Cromwell, *Seminole*	1923	5,465		56,094,746	1,059,204		495	3	242		242
407	Cromwell, East, *Seminole*	1940	300		151,750	151,750		12	12	12	y	y
408	Cromwell, South, *Seminole*	1937	80		399,157	65,148		8		8		8
409	Dora, *Seminole*	1935	1,260		4,225,469	736,758			9	108		108
410	Earlsboro, *Seminole*	1926	5,235		124,123,961	1,503,894		497	1	175		175
411	Earlsboro, East, *Seminole*	1929	2,105		38,103,959	695,034		185		94		94
412	Earlsboro, North, *Seminole*	1936	460		3,876,049	1,226,466		36	3	36		36
413	Earlsboro, South, *Seminole*	1930	430		8,626,052	191,784				18		18
414	Grayson, *Seminole*	1935	530		1,583,295	375,882				35		35
415	Hazel, *Seminole*	1938	330		368,697	90,768		21		21		21
416	Jackson, *Seminole*	1925	735		709,198	35,502			2	14		14
417	Keokuk, *Seminole*	1933	2,585		10,558,839	1,098,366		107		101	y	y
418	Konawa, *Seminole*	1929	1,695		14,853,574	398,940		124	2	99		99
419	Konawa, East, *Seminole*	1936	225		195,195	9,150				6		6
420	Konawa, South, *Seminole*	1938	140		259,240	213,378			7	19		19
421	Konawa, West, *Seminole*	1938	220		446,166	135,420		15	4	15		15
422	Little River, *Seminole*	1927	4,625		109,479,385	2,416,698		595	7	242		242
423	Little River, East, *Seminole*	1928	910		16,487,217	244,854				64		64
424	Little River, Southeast, *Seminole*	1940 1940	40		5,342	5,342		2	2	2	y	y
425	Little River, West, *Seminole*	1938	270		623,147	215,208				12		12
426	Mission, *Seminole*	1928	1,570		25,024,866	460,794		122	1	66		66
427	Rosana, *Seminole*	1924	505		y[1]	201,300			3	20		20
428	Sancho, *Seminole*	1929	120		315,708	11,712			1	6		6
429	Sasakwa, *Seminole*	1927	1,145		10,611,125	424,926		102	1	59		59
430	Sasakwa Townsite, *Seminole*	1933	175		2,233,321	129,564				8		8
431	Searight, *Seminole*	1926	2,110		33,865,593	428,952		144		61		61
432	Searight, East, *Seminole*	1939	80		147,326	44,286				4		4
433	Searight, North, *Seminole*	1934	470		3,255,554	299,754		19		14		14
434	Seminole City, *Seminole*	1926	4,635		126,609,618	2,507,832		396	2	206		206
435	Seminole, East, *Seminole*	1926	1,865		7,904,292	427,122		132	3	97		97
436	Seminole, North, *Seminole*	1940			6,477	6,477				2	y	y
437	Seminole, West, *Seminole*	1935	385		12,511,562	503,250		30	2	25		25
438	Swan, *Seminole*	1938	10		11,525	2,562		1		1		1

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In. Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
391			38	Misener, Hunton, Simpson	Miss, Ord, Sil-Dev	S, L	Por	4,130	4,140	10	A	Wilcox	4,330
392			34	Senora	Pen								
393			34	Hunton	Sil								
394			32	Earlsboro	Pen	S		2,862	2,883	21			
395			34	Earlsboro	Pen	S	Por			y	y		
396			31	Wilcox	Ord	S		4,839	4,844	5			
397			36	Simpson	Ord			4,853	4,886	33			
398			38	Various	Pen, Ord, Sil-Dev	S, L	Por	y	y	y	y		
399			37	Simpson	Ord	D		5,125	5,238	113			
400			36	Earlsboro	Pen	S							
401			36	Various	Mis, Ord, Sil-Dev	S, L		2,500	4,250				
402			36	Cromwell, Booch, Gilcrease	Pen	S					ML		
403			40	Cromwell	Pen	S	Por	3,630	3,615	20	A	Cromwell	
404			40	Various	Pen, Ord, Sil-Dev	SL	Por			30	A		
405			40	Misener, Hunton, Wilcox	Mis. Ord Sil-Dev	S, L	Por	4,180	4,205		A	Wilcox	4,210
406			37	Various	Pen, Ord	S	Por		3,400		AF	Wilcox	4,226
407			38	Cromwell	Pen								
408			37	Wilcox	Ord	S		4,176	4,189	13			
409			35	Boggy, Calvin	Pen	S		2,947	2,959				
410			38	Earlsboro, Wilcox, Hunton	Pen, Ord, Sil-Dev	S, L		y	y	y			
411			39	Calvin, Hunton, Wilcox	Pen, Ord, Sil-Dev	S, L		y	4,250	y			
412			41	Hunton, Wilcox	Sil-Dev, Ord	L	y	y	y	y	A		
						S	Por	4,640	4,650	10	A	Wilcox	4,680
413			39	Calvin, Hunton, Wilcox	Pen, Ord, Sil-Dev	S, L	Por	4,200	4,225	25	A	Wilcox	4,225
414			40	Simpson	Ord		y	4,030	4,050	20	y	y	y
415			y	Thurman, Boggy	Pen	S		2,991	3,003	12	y		
416			38	Booch	Pen	S		y	y	y			
417			40	Misener, Hunton, Wilcox	Mis, Ord, Sil-Dev	SL	y			y	y	Wilcox	4,483
418			36	Earlsboro, Cromwell, Simpson	Pen, Ord	S		y	y				
419			39	Earlsboro	Pen	S		y	y	y			
420			37	Hunton, Wilcox, Viola	Sil-Dev, Ord	S, L							
421			36	Boggy, Calvin	Pen	S		2,697	2,714	17			
422			38	Various	Pen, Ord	S	Por	y	4,100	y	y		
423			36	Various	Pen, Ord	S	y	y	y	y	y		
424			38	Senora	Pen								
425			39	Wilcox	Ord	S		4,378	4,380	2			
426			39	Hunton, Wilcox	Pen, Ord	S, L		y	4,300	y			
427			38	Booch	Pen	S		3,034	3,054	20			
428			37	Gilcrease, Cromwell	Pen	S		y	y	y			
								3,261	3,290	29			
429			36	Various	Pen ,Ord	S, L		2,793	4,187				
430			37	Wilcox	Ord	S	Por	4,047	4,050	3	y		
431			38	Hunton, Wilcox	Sil-Dev, Ord	S, L	Por	4,120	4,325	y	y		
432			39	Cromwell	Pen	S		3,775	3,791	16	y		
433			32	Wilcox	Ord	S	y	4,596	y	y	y		
434			39	Various	Pen, Mis, Sil-Dev, Ord	S, L	Por				y	y	
435			38	Cromwell, Hunton, Wilcox	Pen, Ord, Sil-Dev	S, L		3,514					
436			38	Senora	Pen								
437			42	Wilcox, Calvin	Ord, Pen	S	Por	4,085	4,115	30	A	Wilcox	4,150
438			36	Thurman		S		2,671	2,691	20			

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift
439	Transco, *Seminole*..........	1926	80		104,143	None				4		4
440	Trough—Deep, *Seminole*....	1937	140		741,921	133,590		16	1	14		14
441	Trough—Shallow, *Seminole*..	1937	250		757,354	100,284		27		25		25
442	Tyrola, *Seminole*...........	1937	100		65,433	10,980		5		5		5
443	Wetley, *Seminole*...........	1927	675		y[1]	34,404				18		18
444	Wewoka, *Seminole*..........	1923	2,015		39,781,812	333,792		232	1	94		94
445	Wewoka, East, *Seminole*....	1927	365		1,728,485	74,298		29		9		9
446	Wewoka, North, *Seminole*...	1940	80		22,288	22,288		2	2	2	y	y
447	Wewoka Townsite, *Seminole*.	1924	345		3,028,229	158,478		40		27		27
448	Wofford, *Seminole*..........	1935	50		632,546	29,646				4		4
449	Miscellaneous, *Seminole*.....	1928	140		96,626	18,300				4		4
450	Aggregate for district of pools marked[1].........				4,831,352							
451	Total Seminole Area......				1,109,446,652	38,891,425				4,716		
	SOUTHEASTERN OKLAHOMA											
452	Brock, *Carter*..............	1922	765		3,432,883	92,232				127		127
453	Caddo, *Carter*...............	1939	40		23,379	12,810				1		1
454	Centrahoma, *Coal*...........	1937	80		67,834	17,934		2		2		2
455	Clarita, *Coal*...............	1937	40		54,615	12,810		4	1	3		3
456	Miscellaneous, *Garvin*.......	1936			15,364	None				1		
457	Citra, *Hughes*..............	1937	20		6,130	None		1		1		
458	Miscellaneous, *Love*.........	1937	40		3,957	732				1		1
459	Byars, *McClain*............	1939	200		287,424	284,382			11	10		10
460	Cumberland, *Marshall*......	1940	1,000		426,445	426,445		13	13	13	13	
461	Enos, *Marshall*.............	1933	265		136,555	12,810				23		23
462	Isom Springs, *Marshall*.....	1931	380		149,237	21,960			3	47		47
463	Kingston, *Marshall*.........	1932	115		16,407	None				9		9
464	Madill, *Marshall*...........	1925	275		1,097,030	16,104				81		81
465	Miscellaneous, *Marshall*.....	1932	20		y[1]	None				1		
466	Ada, East, *Pontotoc*.........	1928	325		236,390	24,888			2	18		18
467	Allen (Shallow), *Pontotoc*....	1913	2,530		8,586,633	130,296				198		198
468	Bebee, *Pontotoc*............	1923	2,530		10,522,546	1,766,682			48	228		228
469	Bebee, East, *Pontotoc*.......	1930	215		345,848	61,122				22		22
470	Conservation, *Pontotoc*......	1927	285		484,013	25,254			2	12		12
471	Fitts, *Pontotoc*..............	1933	5,955		88,875,379	6,057,666		989		805		805
472	Fitts, North, *Pontotoc*.......	1934	150		505,138	38,430				15		15
473	Fitts, South, *Pontotoc*.......	1937	205		359,972	90,036				23		23
474	Fitts, West, *Pontotoc*........	1937	175		355,716	68,076				13		13
475	Francis, *Pontotoc*...........	1918	60		x[1]	240				1		1
476	Francis, West, *Pontotoc*......	1917	135		x[1]	3,660			2	6		6
477	Jesse, *Pontotoc*.............	1935	1,235		4,246,201	779,214			1	66	y	y
478	Oakman, *Pontotoc*..........	1935	60		23,448	3,660			1	5		5
479	Steedman, *Pontotoc*.........	1920	50		23,310	491				1		1
480	Steedman, North, *Pontotoc*...	1928	305		1,573,157	87,474				14		14
481	Miscellaneous, *Pontotoc*......	1936	60		8,343	None				3		3
482	Aggregate for district of pools marked[1]..........				225,687							
483	Total Southeastern Oklahoma..................				122,089,041	10,035,408				1,750		
484	Sayre, *Beckham*............	1923			304,519	Abandoned in 1937				1		1

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
439			36	Calvin, Senora	Pen	S		2,159	2,174	15			
440			36	Simpson, Wilcox	Ord	S		3,500 3,781	y	y			
441			33	Earlsboro	Pen	S		2,347	2,360	13			
442			37	Hunton	Sil-Dev	L		3,317	y	y			
443			35	Hunton	Sil-Dev	L		2,420	2,585	165			
444			37	Cromwell, Hunton, Wilcox	Pen, Ord, Sil-Dev	S, L	Por						
445			38	Hunton, Wilcox	Sil-Dev, Ord	S, L		4,214	y	y			
446			y	Wilcox	Ord								
447			38	Various	Pen, Ord, Sil-Dev	S, L							
448			40	Boggy, Wilcox	Pen, Ord	S		y	y	y			
449			y	Senora, Hunton, Calvin	Pen, Sil-Dev	S, L							
450													
451													
452			32	Ordovician, Arbuckle	Cam, Ord	S	Por		2,100		AF	Ord Lime	3,000
453			35	Woodford	Mis	S		4,170	4,324	154			
454			38	Viola	Ord	L		5,970	6,235	265			
455			39	Atoka		S		790	836	46			
456			y										
457			34	Bromide, McLish	Ord	S		5,755	5,994	y			
458			35	Viola	Ord	L							
459			37	Viola	Ord	L		3,485	3,623	138			
460			37	Bromide	Ord								
461			26	Arbuckle, Preston	Cam, Ord								
462			26	Stray sand		S		537	540	3			
463			26	Cretaceous, Trinity	CreL								
464			40	Bilbo, Arbuckle	Cam, Ord	S		402					
465			y										
466			27	Boggy, Senora	Pen	S		1,790	1,795	5			
467			30	Allen									
468			36	Boggy, Hunton, Viola	y Sil, Ord	S L		1,600 2,300 y	1,750 2,407 y	150 107 y			
469			35	Senora, Hunton, Viola-Simpson	Pen-Sil, Dev-Ord	SL		1,830	1,839	9			
470			30	Boggy, Hunton	S L			y 2,656	y 2,675	y 19		Wilcox	3,062
471			39	Various	Pen-Sil, Dev-Ord	SL							
472			32	McAlester, Gilcrease	Pen	S		1,767	y	y			
473			35	Gilcrease, Hunton, Viola	Pen, Sil-Dev, Ord	S L		y 3,876	y 4,181	y 305			
474			39	Cromwell	Pen	S		3,021	3,110	89			
475			26	Allen, Senora	Pen			1,200	2,000				
476			27	Allen, Senora	Pen								
477			40	Hunton, McLish	Sil-Dev, Ord	L S	y, Por	3,884 4,620	3,910 4,633	26 13	AF		
478			29	Boggy	Pen	S		1,160	1,169	9			
479			31	Boggy	Pen								
480			31	Boggy	Pen								
481			36	Hunton	Sil-Dev	L							
482													
483													
484			38	Deese	Pen	S	Por			y	y		

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940, Completed	Number of Oil and/or Gas Wells: End of 1940, Producing Oil[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
485	Binger, *Caddo*	1934	80		71,013	7,320		1		1		1
486	Cement, *Caddo*	1917	4,505		19,533,593	2,477,454		431	50	319	y	y
487	Miscellaneous, *Caddo*	1925			y[1]	Abandoned in 1937						
488	Ed Cox, *Carter*	1925	770		646,334	77,226			3	46		46
489	Fox, *Carter*	1917–35	1,100		14,197,839	462,990				98		98
490	Graham, *Carter*	1917	2,990		26,050,787	378,810				273		273
491	Healdton, *Carter*	1913	7,550		187,467,331	3,178,710		2,353	13	1,912		1,912
492	Hewitt, *Carter*	1919	3,775		87,970,769	1,809,138		979	66	805		805
493	Sholem—Alechem, *Carter*	1923	4,760		36,967,436	998,082		400	4	319		319
494	Tatums, *Carter*	1927	2,660		15,569,196	667,584		247		220		220
495	Tussy, *Carter*	1933	985		3,073,469	485,682			3	85		85
496	Wheeler, *Carter*	1916	755		x[1]	8,052			1	72		72
497	Wildcat Jim, *Carter*	1914	1,235		x[1]	166,896				88		88
498	Miscellaneous, *Carter*	1938	40		y[1]	2,196				2		2
499	Hanbury, *Comanche*	1920	280		y[1]	1,830				5		5
500	Lawton, *Comanche*	y			y[1]	3,294			13	96		96
501	Walters, *Cotton*	1917	3,790		25,123,269	330,498			1	248		248
502	Robberson, *Garvin*	1921	2,410		14,859,020	350,994		328		176		176
503	Knox, *Grady*	1924	1,990		14,359,355	711,504		261	16	168		168
504	Miscellaneous, *Grady*	1923	40		y[1]	0				1		1
505	Altus, *Jackson*	1934	1,740		1,205,751	369,660			39	98	y	y
506	Tipton, *Jackson*	1935	750		1,456,106	364,902			4	56	y	y
507	Oscar, *Jefferson*	1924	685		9,751,813	539,118				188		188
508	Seay, *Jefferson*	1924	325		512,755	21,960			1	49		49
509	Spring, *Jefferson*	1924	265		y[1]	121,512				37		37
510	Hobart, *Kiowa*	1939	700		91,089	36,966			7	10	y	y
511	Stockton, *Love*	1937	80		40,427	10,248				1		1
512	Comanche, *Stephens*	1918	925		10,214,406	198,738			6	159		159
513	Cruce, *Stephens*	1926	100		y[1]	6,954				5		5
514	Doyle, *Stephens*	1921–37	315		y[1]	180,438			9	34		34
515	Doyle, West, *Stephens*	1939	100		58,221	32,940				2		2
516	Duncan, North, *Stephens*	1920	1,260		4,091,463	147,498				92		92
517	Duncan, West, *Stephens*	1919	910		5,781,637	121,878				72		72
518	Empire, *Stephens*	1920	2,630		y[1]	519,354			3	271		271
519	Loco, *Stephens*	1915	575		1,463,901	62,952				62		62
520	Milroy, Deep, *Stephens*	1937–39	40		316,732	109,800		1		1		1
521	Milroy, Shallow, *Stephens*	1916	800		3,245,191	96,624			3	144		144
522	Palacine, *Stephens*	1929	120		147,120	16,470				7		7
523	Rainola, *Stephens*	1921	150		y[1]	36,600			1	23		23
524	Velma, *Stephens*	1917	3,610		5,810,356	267,180			8	635		635
525	Woolsey, *Stephens*	1922	170		y[1]	23,790				19		19
526	Miscellaneous, *Stephens*	1935	80		y[1]	6,222				2	y	y
527	Frederick, *Tillman*	1937–39	180		26,355	8,418			2	2		2
528	Frederick, West, *Tillman*				1,196,571	497,028			8	21	y	y
529	Red River Bed, *Tillman*	1920	500		y[1]	127,368				90		90
530	Aggregate for district of pools marked[1]				37,251,532					7,014		
531	Total Southwestern Oklahoma				528,855,356	16,042,878						
532	Total Oklahoma				4,776,872,054	150,014,249			962	54,895		

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
485				Deese	Pen								
486			34	Various	Per, Pen	S		1,900	1,600				
487													
488			22	Pontotoc and Deese	Pen	S		1,250	2,910	30			
489			31	Simpson, Oil Creek, Fox sand	Pen, Ord	S	30	2,200	2,500		A		
490			31	Deese	Pen	S	28–30			45–70	A	Dornicks Hills	5,180
491			31	Various	Pen, Ord	SL		920	3,500		AF	Arbuckle	*x*
492			34	Hewitt, Viola	Pen, Ord	S	15–20	920	2,700		AF	Arbuckle	*x*
493			29	Deese, Hoxbar	Pen	S	30	1,890	4,000		A		
494			27	Deese, Arbuckle	Pen, Ord	S	30			60	AM DL		
495			23	Deese	Pen	S	Por			*y*	A		
496			*y*	Pontotoc	Pen	S	*y*				A		
497			24	Pontotoc, Deese	Pen			1,552	2,890				
498			*y*	Pontotoc	Pen								
499			38	Various		Gw S		1,640	2,100				
500			*y*										
501			34	Cisco, Hoxbar				2,100	2,400				
502			23	Pontotoc, Simpson	Pen, Ord	SL	*y*	1,200	1,900		A		
503			35	Pontotoc	Pen	S	15–20	1,700	2,200	15	AF		8,963
504			40	Pontotoc	Pen								
505			41	Granite wash	Pen	GW	Por			30	D		
506			40	Canyon, Reworked Arbuckle	Ord	L		*y*	*y*	*y*			
507			33	Glenn	Pen	S		1,180	1,610	25			
508			35	Cisco, Hoxbar				1,100					
509			35	Hoxbar				2,095	2,101	6			
510			35	Pontotoc, Conglomerate		L		1,091	1,107	16			
511			35	Unidentified		S		6,893	6,927	34			
512			34	Stray, Wilson, Pace		S		1,400	1,800				
513			30	U. Pen	U Pen	S		800	1,900				
514			*y*	Permian, Hoxbar, Deese	Per, Pen			1,100	1,250				
515			42	Deese	Pen	S		5,578	5,614	36			
516			36	Thomas				1,700	2,300				
517			33	Brown, Blaydes				1,700	2,300				
518			39	Hoxbar, Pontotoc, etc.				1,600	2,300				
519			23	Pontotoc, Deese	Pen	S		850	1,550				
520			43	Oil Creek, Hunton	Sil-Dev			7,554	7,625	71			
521			26	Permian Unconformity, Glenn	Per, Pen			340 580 1,000	370	10–5 25			
522			36	Pennsylvanian, Arbuckle	Ord, Pen								
523			36	Smith, Brown	Pen			2,000 2,100	2,025 2,155	25 55			
524			26	Permian, Glenn	Per, Pen	S		350 900	1,700 2,300				
525			32	Permian Glenn	Per, Pen	S		1,300 1,750	1,850	100			
526			36	Deese	Pen	S							
527			*y*	Canyon, Strawn	Ord	LS		3,081					
528			40					4,215	4,218	3			
529			39	Cisco				1,540	1,700	19			
530													
531													
532													

a unit with a pressure maintenance program in effect.

Byars.—In this late 1939 discovery, 11 oil wells, with an average initial of 1000 bbl., and two dry holes were completed during the year 1940. Despite the high initial rate, however, the wells were producing an average of only 10 bbl. at the end of the year. The Viola limestone is the producing horizon.

Bebee.—Illustrative of development in old pools that is sustaining Oklahoma's production remarkably well is the Beebe pool, where 48 oil wells having an average initial production of 150 bbl. were completed in 1940. Daily average production was thereby increased from 2400 bbl. in 1939 to 4800 in 1940.

Oklahoma City.—Development in this great pool continued during the year, principally between the older south area and the more recently developed Mansion area around the State Capitol; 29 oil wells averaged 500 bbl. daily per well. Production was sustained at 97,600 bbl. daily, a decline of only 200 bbl. from the previous year's daily rate. A serious effort is being made to unitize the Wilcox sand producing area, from which almost all of the current production is coming, in order to institute repressuring operations. This is undoubtedly one of the most ambitious repressuring projects ever conceived by Mid-Continent operators. The Oklahoma City pool has produced more than 500 million barrels of oil, of which approximately 385 million barrels have come from the Wilcox sand, which averages 100 ft. in thickness over an area of 7000 acres. Further progress on the project is dependent on legislative action resulting in compulsory unitization, as the diversity of ownership of both working interest and royalties makes private agreements impossible of attainment.

St. Louis.—The St. Louis pool continued as the most active area in the Greater Seminole district, with the completion of 38 oil wells averaging 400 bbl. initial. Production declined from 31,100 bbl. daily in 1939 to 25,800 daily in 1940.

TABLE 2.—*Summary of Drilling Operations in Oklahoma*

Important Wildcats Drilled in 1940

	County	Location			Total Depth, Ft.	Surface Formation	Deepest Horizon Tested
		Sec.	Twp.	Rge.			
1	Marshall	28	5 S	7 E	5,640	Washita (Cretaceous)	Simpson (Ordovician)
2	Okfuskee	36	11 N	8 E	3,476	Francis (Pennsylvanian)	Cromwell (Pennsylvanian)
3	Lincoln	6	15 N	5 E	4,635	Pennsylvanian and Permian	Wilcox (Ordovician)
4	Logan	3	17 N	4 W	4,908	Lower Enid (Permian)	Lower Layton (Pennsylvanian)
5	Pottawatomie	4	11 N	6 E	4,688	Pennsylvanian and Permian	2nd Wilcox (Ordovician)
6	Creek	31	15 N	7 E	4,119	Pawhuska, Elgin, etc. (Pennsylvanian)	2nd Wilcox (Ordovician)
7	Seminole	3	11 N	8 E	4,157	Francis (Pennsylvanian)	Sylvan (Silurian)
8	Stephens	9	1 S	4 W	6,310	Clear Fork and Wichita (Permian)	Springer (Pennsylvanian)
9	Tillman	10	2 S	19 W	6,750	Clear Fork and Wichita (Quaternary)	Simpson (Ordovician)
10	Marshall	14	6 S	6 E	5,890	Washita (Cretaceous)	Arbuckle (Ordovician)
11	Garvin	22	1 N	1 E	5,005[1]	Pontotoc (Pennsylvanian and Permian)	(Pennsylvanian)
12	Washita	16	8 N	16 W	8,000	Day Creek Dolomite and Whitehorse sandstone (Permian)	Granite wash
13	Beckner	4	9 N	25 W	3,718	(Quaternary) Woodward	(Pennsylvanian)
14	Dewey	31	18 N	14 W	9,475	Woodward (Permian)	Lower Cherokee (Pennsylvanian)
15	Kingfisher	15	18 N	9 W	9,405	Upper Enid (Permian)	Marshall (Ordovician)
16	Kingfisher	30	18 N	5 W	8,226	Lower Enid (Permian)	Wilcox (Ordovician)
17	Garfield	21	21 N	4 W	6,543	Lower Enid (Permian)	Wilcox (Ordovician)
18	Garfield	12	21 N	3 W	5,750	Lower Enid (Permian)	2nd Wilcox (Ordovician)
19	Garfield	23	23 N	6 W	6,939	{ (Quaternary) { (Quaternary) (Permian)	Wilcox (Ordovician)

[1] f = flow pressure.

Cement.—In this pool, which has been consistently active for the past three or four years, 46 oil wells were added in 1940. Average initial production was approximately 1000 bbl. per well. Four gas wells and 16 dry holes were also completed in the pool, the gas wells averaging 35 million cu. ft. initial. Production is greatly curtailed because of limited pipe-line facilities, the average being 6770 daily, an increase of 1750 bbl. over the 1939 average.

Of the 227 wildcat wells drilled in the state during the year, 19 have been listed on Table 2. Most of the discoveries were in the immediate proximity of old producing areas and this is true also of the bulk of wildcatting during the year. Western and southwestern Oklahoma were accorded increased attention and the discovery of the Cumberland pool in Marshall County naturally stimulated interest in the southernmost part of the state. The wells listed were selected because they have had or are expected to have the greatest effect on immediate drilling programs, because they were drilled to considerable depths, or were located in areas where the information gained by their drilling was considered of most importance.

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Drilled by	Initial Production per Day: Oil, U. S. Bbl.	Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.: Casing	Pressure, Lb. per Sq. In.: Tubing	Remarks
1	Pure Oil Co.	4,518		1,150	1,150	PB 5,100
2	Reese Drilling	456		800		
3	Summit Drilling et al.	311	36/64	*f*[1] 500	*f* 300	PB 3,555
4	Dancinger Oil Co.	200	½	*f* 500		
5	Berkey et al.	124				PB 3,278
6	Shell Oil Co.	177				
7	Droppleman et al.	800		*f* 340		PB 3,612
8	Sun Oil Co.					Dry and abandoned
9	Cline et al.					Dry and abandoned
10	Johnson et al.					Dry and abandoned
11	Kerlyn Oil Co.					Dry and abandoned
12	Continental Oil Co.					Dry and abandoned
13	Fred Coogan					Dry and abandoned
14	Magnolia Petr. Co.					Dry and abandoned
15	Olson Drilling					Dry and abandoned
16	Phillips Petr. Co.					Dry and abandoned
17	Fain Drilling et al.					Dry and abandoned
18	Magnolia Petr. Co.					Dry and abandoned
19	Champlin Ref. Co.	75				Dry and abandoned

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	330	93
Number of oil wells completed during 1940	919	43
Number of gas wells completed during 1940	156	16
Number of dry holes completed during 1940	483	168

Oil and Gas Development in Northern and Central Pennsylvania during 1940

By Arthur C. Simmons * Member A.I.M.E.

Production of oil within the state of Pennsylvania in 1940 was slightly more than the 1939 total, and this increase was due entirely to the new flush Music Mountain field south and west of the main Bradford pool. The influence and magnitude of Music Mountain production will be separately described, inasmuch as it is an important producing unit within the state.

Production

Bradford Field

The production listed herein for Bradford field includes only the part of the field that is within the state of Pennsylvania. Approximately 4000 bbl. per day, or 10 per cent of the total production of Bradford field comes from Cattaraugus County, New York, and should properly be attributed to production obtained within the New York state area, although locally and economically the Bradford field, situated both in New York State and Pennsylvania, is included as a single statistical unit.

The 1940 average production in the Bradford field was 34,831 bbl. per day, as compared with a daily average in 1939 of 35,340 bbl., or a decrease from 1939 of 509 bbl. per day. The decrease in production from the Pennsylvania portion of the Bradford field would have been more pronounced if a portion of the crude from the Music Mountain field were not included with the statistics for Bradford field. The decline can be attributed largely to the fact that more properties of lower average recovery were being drilled in 1939 and 1940 than in previous years, and apparently a subnormal amount of drilling occurred in 1938 and 1939, when about 2100 wells were drilled each year. The full effect of the 1940 drilling is not felt immediately and undoubtedly will affect the producing period of 1941.

It appears probable that the water-flood area in the Bradford field has reached a definite peak unless some unusual economic condition should cause abnormal prices and an excessive rate of development such as occurred in 1936 and 1937. Virtually all of the production in the Bradford field was obtained by water-flooding methods, as natural or stripper wells are uneconomical and air and gas repressuring have not proved so efficient as water-flooding as a secondary recovery method.

Central and Southern Pennsylvania

Central and southern Pennsylvania produced a total of 4,604,763 bbl. of oil during the calendar year of 1940; that is, an increase over the 1939 total of 166,728 bbl. The daily average production was 12,581 bbl., or an increase over 1939 of 422 bbl. per day. Table 1 includes the total oil production for the state of Pennsylvania for the years 1937 to 1940, inclusive, and the daily average for each of these years. It is impractical to make a complete subdivision by districts, consequently the only segregation is the production from the Bradford field (within the state of Penn-

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sylvania) and oil production from central and southern Pennsylvania. All of the increase during 1940 can be attributed to the production from Music Mountain, for if that production had not been available the remainder of Pennsylvania would have shown a decline.

Table 1.—*Oil Production, State of Pennsylvania*

	Wells Completed, Bradford Field[a]	Change	Oil Production, Bradford Field, Bbl.[b]	Change	Oil Production, Central and Southern Pennsylvania, Bbl.	Change	Oil Production, State of Pennsylvania, Bbl.	Change
Total:								
1937......	4,112		15,076,909		4,108,100		19,185,109	
1938......	2,148	−1,964	13,417,102	−1,659,807	4,008,923	− 99,177	17,426,025	−1,758,984
1939......	2,114	− 34	12,899,104	− 517,998	4,438,035	+429,112	17,337,139	− 88,886
1940......	3,004	+ 890	12,748,279	− 150,825	4,604,763	+166,728	17,353,042	+ 15,903[c]
Daily average:								
1937......			41,300		11,255		52,555	
1938......			36,759	− 4,541	10,983	− 272	47,742	− 4,813
1939......			35,340	− 1,419	12,159	+ 1,176	47,499	− 243
1940......			34,831	− 509	12,581	+ 422	47,412	− 87[c]

[a] Includes oil and water-intake wells and New York state portion of Bradford field.
[b] Pennsylvania production only.
[c] Variance between total production and daily average occasioned by 365-day year in 1939 and 366-day year in 1940.

Except in the Clarendon field, Warren County, where water-flooding has been used with some success, all of the production in central and southern Pennsylvania was obtained from "natural stripper" wells and by air-gas repressuring. It would appear from a study of annual productions that the effect of air and gas repressuring is not sufficient to overcome the normal gradual decline in the remainder of Pennsylvania.

Music Mountain

The Music Mountain field, situated about 9 miles southwest of the city of Bradford and south of the main Bradford pool, was discovered in August 1937. However, because of economic conditions and the state of development, the 1937 and 1938 productions were nominal. The production from the Music Mountain field in 1939 has been estimated at 857,080 bbl.,* or a daily average for the entire year of 2348 bbl. The production from that field for 1940 is estimated at 1,229,375 bbl.,* or a daily average of 3359 bbl. The 1940 production is approximately 7 per cent of the total production within the state of Pennsylvania, and because of the rarity of new discoveries in the state of Pennsylvania, the Music Mountain production becomes important in any consideration of the total production of the state.

Some indication of the producing capacity of this field is given in the following table of estimated daily average production by months for the calendar year 1940:

	Bbl.		Bbl.
Jan..............	5,900	July............	280
Feb..............	6,100	Aug............	1,000
Mar..............	6,100	Sept............	1,050
Apr..............	5,500	Oct.............	1,200
May..............	5,000	Nov............	2,350
June.............	1,055	Dec............	4,840

With a 1940 daily average production from Music Mountain of approximately 1000 bbl. per day more than in 1939, it is apparent that without it Pennsylvania production would have shown a sharp decline. Part of the production of Music Mountain field is included with the production for Bradford field and part with that of central and southern Pennsylvania, consequently it

* *Producers Monthly.*

is difficult to separate from the production for the Bradford field the production from the Music Mountain field included therein, and likewise in the central and southern Pennsylvania classification.

Crude Prices and Stocks

A price change occurred on Jan. 1, 1940, wherein the price of Bradford Allegany crude oil was increased from $2.50 per barrel to $2.75 per barrel; and in Table 2 are included all price changes in the Pennsylvania Grade Crude producing area. The wide swing in prices is attributable to a combined condition of crude storage and lubricant prices. The average price in the Bradford Field of $2.318 is approximately 26¢ higher than the average price realized in 1939, marking 1940 as one of the better years in the past decade.

The storage of Pennsylvania Grade crude oil increased during April, May, July and August, and decreased during all other months. The low point was reached on March 31, 1940, when there was a total of 4,010,000 bbl. of Pennsylvania Grade crude oil in storage. At the end of the year, crude stocks were 4,034,000 bbl., and the low value of 4,010,000 bbl. is the lowest point of crude storage in recent records. It is necessary to include in crude storage the crude equivalent of the lubricating stocks, and the crude oil plus the crude equivalent of the lubricants increased from a low in December 1939 of approximately 7,500,000 bbl. to a maximum in July, August and September 1940 of approximately 9,800,000 bbl. It appears that regardless of slightly excessive stocks of lubricants, the Pennsylvania Grade area entered 1941 in a favorable position for the reason that crude storage is at a low point and lubricant stocks have decreased from their excessive amounts reached in the fall of 1940.

Drilling and Development

Well completions in the Bradford field totaled 3004 during 1940, which is a gain of 890 over the 1939 total of 2114. This record of well completions includes both oil and water-intake wells within the entire Bradford field and cannot be segregated except on a pro rata basis into the Pennsylvania portion of the Bradford field and the Cattaraugus County, New York, section of the Bradford field. The excessive drilling of 1937, when 4112 wells were completed, was entirely liquidated by the end of 1939, and 1938 and 1939 completions were probably subnormal. It appears probable that the 1941 well completions within the Bradford field will equal and perhaps exceed the total of 3004 wells drilled in 1940. Approximately one-half of these wells are water-intake wells and the remainder are producing oil wells. Approximately 120 wells were drilled in the Music Mountain field during 1940, with a segregation as follows: producing wells, 109; gas wells, 3; dry holes, 2; gas-intake wells, 6. Further attempts were made to extend the producing area of the Music Mountain field, but these were unsuccessful.

Table 2.—*Price Changes during* 1940

Date	Bradford	Allegany	S. West Pa.	West Va.	Ohio
Jan. 1	$2.75	$2.75	$2.40	$2.34	$2.30
May 22	2.50	2.50	2.15	2.09	2.05
June 18	2.25	2.25	1.90	1.84	1.80
July 12	2.00	2.00	1.65	1.59	1.55
Aug. 28	1.85	1.85	1.50	1.44	1.40
Nov. 12	2.00	2.00	1.65	1.59	1.55
Dec. 17	2.15	2.15	1.80	1.74	1.70
Average	2.318	2.318	1.969	1.909	1.869

Oriskany Gas

Many unsuccessful tests were drilled to the Oriskany horizon during 1940, and no new fields of major consequence were discovered. The older fields are still productive and one interesting operation in gas storage is being conducted. The Farmington field, Farmington township, Tioga County, Pennsylvania, was the first large Oriskany gas field within the state of Pennsylvania, and a portion of this field is being successfully used for gas storage, thereby minimiz-

ing and alleviating peak-load conditions on other producing fields and distributional facilities.

New Developments

Few, if any, radically new developments occurred in the water-flooding districts of Pennsylvania, although with the gradual exhaustion of natural gas as a fuel supply on water-flooding operations, there is more and more emphasis on the use of purchased electric power. There is a decided trend toward the use of individual electric pumping units, and many water-pressure plants are operated by electric power.

Extensive research on water-flooding is being continued by the Bradford District Producers Association to find a better technique in the production of oil by water-flooding methods.

Oil and Gas Developments in Southwestern Pennsylvania during 1940

By John T. Galey,* Member A.I.M.E.

Production of crude oil for 1940 in southwestern Pennsylvania was off nearly 70,000 bbl., largely as a result of the great number of abandonments, together with the lack of extension of the Washington and Green County pools. Oil wells completed numbered 51, which is 26 more than last year, but the total initial production of 259 bbl. is only 18 bbl. greater than in 1939. There was an increase of 72 over last year for a total of 209† gas wells. However, 68† dry holes were drilled, which is 40 more than a year ago. Thus, 328† wells were drilled during the year, and rigs are erected or drilling is progressing on 59† more.

Shallow Development

Oil.—Butler County led in number of oil wells completed, with a total of 27 for an initial production of only 69 bbl. Washington County, with 12 new oil wells, one of which made 40 bbl. from the Fifth sand in S. Franklin township, has 95 bbl., while in Allegheny County 9 wells gave an initial of 86 bbl. for the highest per well average in the area. This initial was given a considerable boost by one 35-bbl. and another 25-bbl. well in West Deer township, where the Fourth sand produced at 1840 feet.

Greene County had only one oil well completed during 1940, and Washington County had 12. The subnormal totals for these counties may be explained by the higher cost of completions and the declining price of crude. The first price change in crude during the year occurred on May 22, when a 25¢ cut was made. A second 25¢ cut was made July 12, and was followed by a 15¢ cut on Aug. 28. This price held until Nov. 12, when there was a restoration of 15¢. On Dec. 17 a second 15¢ increase was put into effect, bringing the price to $1.80 per barrel.

Gas

The large increase in the number of gas wells completed may be attributed to three factors; namely, the recently discovered production possibilities of moderately deep, hitherto little tested horizons, together with increased demand and price. The latter has been made possible by a recent decision of the court, which ruled restraining the Public Service Commission's prohibition of a raise in the minimum monthly charge to small consumers by one of the major gas companies. A portion of the revenue derived in this manner is being passed along to the producer in the form of higher prices in the field. This higher field rate will remain in effect until a new ruling is made, when it will be reduced in proportion to the reduction of the monthly minimum charge.

In an effort to extend the Chambers Dam Fifth sand oil pool southwest from Amwell township, Washington County, several wells have been drilled. One of these, in Morris township, Washington County, had an initial of 3.2 million cu. ft. open flow from the Big Injun sand. This indicates an entirely new productive area for the latter horizon.

Allegheny County had one spectacular well in South Fayette township—at a depth of about 2500 ft. a 4-million-cu. ft.

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* Oil and Gas Operator, Pittsburgh, Pa.

† These figures include both new and old wells drilled to deeper horizons.

gasser blew in. Although the rock pressure was 600 lb., the well suffered a rapid decline and now produces slightly more than 0.1 million cu. ft. per day.

Armstrong County leads in number of gas wells completed, with a total of 59. Many of these were small wells drilled to the Bradford sand. Only one had an initial of as much as 1.4 million cu. ft. and that was from the Murraysville sand at a depth of 1354 ft. in Kiskiminitas township.

On a southwestern extension of the trend in Monongahela township, Greene County, one 4-million, two 5-million, and one 1-million-cu. ft. wells were encountered in the Big Injun. The closed-in rock pressure is 275 lb. per sq. in., and while that is not virgin pressure, the area now shown to be productive in Fayette and Green Counties is large enough to be of real consequence.

Jackson township, Greene County, had one well with an initial of nearly 2 million cu. ft. from the Fifty-foot sand at 2950 ft., while the same sand gave an open flow of over 1.5 million cu. ft. from a depth of 2420 ft. in Somerset township, Washington County. The latter locality also had a 3.6-million-cu. ft. gas well in the Fourth sand at 2815 feet.

TABLE 1.—*Wells Drilled for Oil and Gas in Southwestern Pennsylvania during* 1940, *Together with Initial Oil and Gas Production Developed*

County	Number Gas Wells	Initial Open Flow, Thousand Cu. Ft.	Number Oil Wells	Initial Production, Bbl.	Number Dry Holes	Drilling as of Dec. 30, 1940
Allegheny	6	4,500	9	86	4	None
Armstrong	59	10,248	1	5	9	14
Beaver	None	None	1	1	2	None
Butler	10	750y	27	69	8	8
Fayette	24	27,958	None	None	1	8
Greene	39	27,393	1	3	4	15
Indiana	24	5,506	None	None	26	3
Lawrence	1	50	None	None	None	None
Washington	24	11,266	12	95	10	6
Westmoreland	22	3,225	None	None	4	5
Total*	209	90,896	51	259	68	59

* Totals include deepening operations.
y Estimated.

A number of good wells were completed in Fayette County; Menallen township had three Big Injun sand completions with open flows of 1 million cu. ft. or better. One well in this township that failed to produce from the Big Injun was drilled to the Fifty-foot sand, where at 1873 ft. an open flow of 1.3 million cu. ft. with a shut-in pressure of 815 lb. per sq. in. was encountered. This is an entirely new productive horizon in this locality and might well prove to be of some extent. Nicholson township had one 2.5-million-cu. ft. Big Injun sand well and another had nearly 0.6 million cu. ft. from the Fifth sand at 2398 ft. An open flow of 0.15 million cu. ft. was encountered in the Bradford sand at 3705 ft. near the Perry-Franklin township line. Thus the ability of several sands below the Big Injun to produce in this area has been demonstrated.

Deep-sand Development

The notable development in deep-sand exploration during the year was the proving of the existence of an Oriskany-sand gas pool at Summit, Fayette County. Deep drilling was confined entirely to Beaver and Fayette Counties during 1940. In Fayette County, where the southeasternmost test in the state is being drilled in Stewart township, on the Gregg Nell tract, a depth of 8002 ft. has been reached. The top of the Tully limestone was encountered at 7790

ft., and indicates that the Onondaga limestone will lie 500 to 700 ft. lower than the depth predicted by the seismograph. However, it is believed that the hole has crossed over to the downthrough side of the fault shown on the surface. This is borne out by the drill cuttings from 7120 to 7440 ft., where serious drilling difficulties prevailed.

Oriskany and obtained approximately 1 million cu. ft. of additional gas. Piedmont Coal & Coke No. 2, a new well, found 2.4 million cu. ft., most of which was from the Oriskany. Four additional wells are drilling to the Oriskany in this pool.

An Oriskany test of a seismograph closure is being made on the Elmer Pflug farm, New Sewickley township, Beaver County. Starting at a surface elevation of 1153 ft., the Onondaga is expected at a depth of 5270 feet.

TABLE 2.—*Deep Drilling in Southwestern Pennsylvania during* 1940[1]

County	Township	Name	Elevation, Ft.	Tully, Top	Onondaga, Top	Oriskany	Lockport	Queenston Red	Total Depth	Remarks
Beaver.......	S. Beaver	Tennis Hrs. No. 1[3]	983	4,243	4,405	4,599–4,670	6,015–6,290	6,799	6,823	Show gas 6260 ft. Red Medina, 6588–6663; White Medina, 6663–6761
Beaver.......	New Sewickley	Pflug No. 1	1,153							Drilling
Fayette......	Stewart	Neel No. 1	2,566	7,790						Shut down 8004 ft.
Fayette......	N. Union	Sorg No. 2	2,511	6,350						Cementing in Marcellus
Fayette......	S. Union	Heyn No. 1[3]	2,316			6,793[4]			6,840	1.4 million[5]
Fayette......	S. Union	Heyn No. 2[3]	2,464			6,834[4]			6,982	2.2 million[5]
Fayette......	S. Union	Heyn No. 3	2,314							Drilling
Fayette......	N. Union	Piedmont Coal No. 1	2,176			7,042[4]			7,058	13 million[5] R. P. 1400 ft.
Fayette......	S. Union	Piedmont Coal No. 2	2,024	5,720	6,381[4] 6,421[2]	6,691[4]			6,817	2.4 million[5] R. P. 2200 ft.
Fayette......	S. Union	Piedmont Coal No. 3	2,405	6,048						Drilling
Fayette......	S. Union	Piedmont Coal No. 4	2,491							Drilling

[1] Including deepening operations.
[2] Top chert.
[3] Deepened.
[4] Producing horizon.
[5] Total initial open flow from Onondaga & Oriskany.

SUMMIT POOL

The second Oriskany-sand pool in southwestern Pennsylvania was proved during 1940 to lie below the Onondaga limestone production at Summit, Fayette County. Piedmont Coal No. 1 well, N. Union township, after finding over 4 million cu. ft. in the Onondaga, was later deepened to the Oriskany, and at 7054 ft. an open flow of 13 million cu. ft. of dry gas was found. It is now believed that the production in this well is separated from that in the main Summit pool. Heyn No. 1, the discovery well, which a year ago was deepened into the Onondaga and yielded a large increase, was drilled into the Oriskany, where an additional 1.4 million cu. ft. was found.

Heyn No. 2, which had been a small well in the Onondaga, was deepened to the Oriskany and obtained approximately 1 million cu. ft. of additional gas.

For the first time in southwestern Pennsylvania and the first time on proven Oriskany closure in Ohio or Pennsylvania, the Lockport dolomite and Medina sands were tested by the James Tennis Hrs. No. 1 well, South Beaver township, Beaver County. The test was unproductive. It is notable that this hole was carried to its total depth of 6823 ft. through only 920 ft. of 8⅝-in. o.d. casing.

GEOLOGICAL DATA

A temperature observation was made on the James Tennis Hrs. No. 1, where 128°F.

was recorded at 4577 ft. and 155°F. at 6800 feet.

Estimated depth of the Lockport dolomite in this well proved to be short of the depth at which it was actually found, which may be attributed to the abnormal thickness of the Salina section. Depth to the Medina was also greater than anticipated, possibly as a result of a combination of the former plus an abnormal thickening of the shale interval between the bottom of the Lockport and the Medina. This abnormal thickening may well be the result of flowage toward the top of the structure, similar to that which takes place in the formation of nonpiercement types of salt domes.

Previous to the deepening of the well, it had been possible to project closed structures from the Oriskany to both the Lockport and the Medina by means of Oriskany-Lockport and Oriskany-Medina convergence. When the well, completed through the Medina, was employed in the convergence picture, the relief of the closure was somewhat diminished, as is indicated from the thickening of the above mentioned intervals. Thus the structure it is possible to project below the Oriskany by means of Oriskany-Lockport and Oriskany-Medina convergence has greater relief than that actually found.

This is the converse of the result obtained by projecting a Berea structure to the Oriskany by means of Berea-Oriskany convergence, for a thinning of the Berea-Oriskany interval over the axis of the structure increases the actual relief over that which it is possible to project.

An interesting observation has been made recently in the Summit pool, Fayette County. In the Piedmont Coal & Coke No. 1 well, South Union township, the Oriskany had little gas, as it was tightly cemented with calcite. The Onondaga limestone rests directly on the Oriskany sand in this well. The Piedmont Coal & Coke No. 2 well, also in South Union township, had loose Oriskany sand and most of the production comes from that horizon rather than from the Onondaga. Here a shale break intervenes between the Onondaga and Oriskany. Sufficient study has not yet been made of all Oriskany wells in the area to determine whether or not some relationship exists between the presence of this shale break and the occurrence of Oriskany production.

Seismograph Work

Several of the major oil companies that of late have come into eastern Ohio are doing seismograph work in the western tier of counties. They have been able to get almost double the number of depth points per day that have been obtainable heretofore. By their rapid method, they have been able to carry long continuous profiles, which have never before been attempted in this part of the country. Several favorable structures have been located apparently, as some large blocks of acreage have been taken.

Production Technology

When the James Tennis Hrs. No. 1 well had proved dry after being drilled through the Medina sand, it was plugged back to the Oriskany sand and acid treatment was attempted in order to increase the production from that formation. Chunks of Oriskany sand, taken from the hole after a shot, were treated, and there was every indication that acidizing would yield some result. However, the tubing immediately above the packer unfortunately collapsed and the treatment was unsuccessful.

Pipe-line Construction

The Pittsburgh subsidiaries of one of the major gas companies several months ago completed a 117-mile pipe line, which will carry West Virginia gas from existing facilities near Monaca, Beaver County, to the New York State line at Knapp Creek, Bradford County. Sixteen-inch welded mill-coated line extends from Monaca 12 miles to near Ellwood City, Lawrence County,

where a dehydration plant and 1000-hp. compressor station having a discharge pressure of 350 lb. per sq. in. was erected. From this point a 12-in. treated composite line was laid for 6 miles north where a tie-in was made with a 10-in. line extending in an easterly direction to the remodeled compressor station at Rimersburg, Clarion County. Twenty-eight miles of 10-in. composite line was constructed from here to Truittsburg and thence to the Iowa compressor station at Brookville, Jefferson County, where a second 1000-hp. compressor station capable of maximum discharge pressure of 800 lb. was erected to supplement existing facilities. Solid welded 8-in. line then extends 71 miles from Brookville through the Bradford oil field to the New York state line.

Construction cost was estimated at $1,800,000 and time required was approximately 10 weeks, which is remarkable considering the terrain traversed. A daily average of approximately 7 million cu. ft. of gas is being carried by the line.

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Oil and Gas Development in the Rocky Mountain District in 1940

By C. E. Shoenfelt,* Member A.I.M.E.

There was a notable decrease in drilling operations in 1940 in all of the Rocky Mountain states except Montana, where the two large fields on the Canadian border, Cut Bank and Kevin-Sunburst, were especially active. The expanding markets for Montana natural gas made necessary the more intensive development of such fields as Bowdoin, Cedar Creek and Devon.

While there were no important oil and gas discoveries in 1940 in any of the Rocky Mountain states, a few small pools were opened, which may constitute separate areas but may prove with later development to be extensions of old fields. Some of the old fields were extended and deeper pay zones were discovered in others. These have given the areas greatly increased oil reserves and therefore are just as important as the discovery of new fields.

The more important of the developments in 1940 are given, by states, in the following paragraphs.

Colorado

Hiawatha Field, Moffat County.—The Mountain Fuel Supply Co. began the development at Hiawatha of its oil reserves, which were discovered in about 1929, and late in the summer oil began moving from the field by truck to the shipping point at Rock Springs, Wyoming.

The Hiawatha field of northwestern Moffat County was discovered in 1927 by the Sormir Petroleum Co., with the completion of No. 1 Florence Wilson for 45,000,000 cu. ft. of gas a day from a Wasatch sand lens at 2200 ft. In later development of the field, oil showings were reported in several wells but no development of this resource was undertaken until 1940, when a test of the oil possibilities was started with the release in April of a location for No. 5-A Wilson on the SW. SW. NW. of sec. 23-12N-100W., on the east side of the field. The well had an initial production of 327 bbl. of oil a day pumping from three Wasatch (Tertiary) sands between 2005 and 2540 ft. It was drilled to 2562 ft., where the 6⅝-in. casing was cemented and gun-perforated at 2005 to 2125 ft., 2260 to 2335 ft. and 2513 to 2540 ft. At the end of the year, this well was averaging 200 bbl. of oil per day, pumping. Two other wells were drilled for oil on Hiawatha during the summer—one a small well of 60 bbl. per day and the other a small gas well.

Powder Wash Field, Moffat County.—The development of the Powder Wash field in northwestern Colorado was resumed in 1940 by the Mountain Fuel Supply Co., with the release of a location for No. 2-A Musser in the CWL.NW.SE. of sec. 4-11N-97W. The Powder Wash field was discovered in 1931 by the Mountain Fuel Supply Co. and the discovery well, No. 1 Musser, on C.NW. of sec. 5-11N-97W., was completed at 2152 ft. in the Hiawatha member of the nonmarine Wasatch formation for an open flow of 34,000,000 cu. ft. of gas per day under a natural pressure of 685 lb. per sq. inch.

Oil was discovered in the Powder Wash field on Nov. 26, 1936, in the company's No. 1 Carl Allen on the NE.SW.SE. of sec. 32-12N-97W. The oil production was

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* Geologist, Petroleum Information, Inc., Denver, Colorado.

TABLE 1.—*Oil and Gas Production in Rocky Mountain District*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
	COLORADO					
1	Berthoud, *Larimer*	1927	510	320	57,242	3,060
2	Boulder, *Boulder*	1902	400		649,784	4,405
3	Florence, *Fremont*	1862	9,000		13,679,326	55,458
4	Ft. Collins, *Larimer*	1923	400		2,186,882	56,395
5	Garcia, *Las Animas*	1927		640		
6	Greasewood, *Weld*	1930	200		463,690	8,857
7	Hamilton, *Moffat*	1924	400		5,681,527	111,217
8	Hiawatha, *Moffat*	1928	640	3,180	147,232	96,674
9	Iles, *Moffat*	1924	600		8,517,903	580,262
10	Model, *Las Animas*	1929		4,380		
11	Rangely, *Rio Blanco*	1919	320		748,954	118,258
12	Thornburg, *Rio Blanco*	1925		350		
13	Tow Creek, *Routt*	1924	200		1,688,357	50,752
14	Walden, *Jackson*	1927	320		85,366	0[1]
15	Wellington, *Larimer*	1924	1,000		4,849,614	71,533
16	Price, *Archuleta*	1934	200		859,414	304,877
17	Wilson Creek, *Rio Blanco*	1938	640		419,451	239,796
	MONTANA					
1	Border, *Toole*	1930	450		1,060,133	28,838
2	Bowdoin-Saco	1916		100,000		
3	Bowes, *Blaine*	1926		3,000		
4	Boxelder, *Hill*	1931		900		
5	Cat Creek	1920			14,840,259	179,298
6	First sand		600			
7	Second sand		240			
	Cedar Creek, *Dawson, Fallon and Wibaux*	1913				
8	First sand			110,000		
9	Second sand					
10	Madison lime	1936	80			
11	Cut Bank, *Glacier*	1932	38,000	55,000	21,002,146	4,109,663
12	Dry Creek, *Carbon*	1930			1,685,164	166,737
13	Frontier			1,760		
14	Cloverly					
15	Elk Basin, *Carbon*	1916	140	40	1,003,784	15,931
16	Hardin, *Big Horn*			2,000		
17	Kevin-Sunburst, *Toole*	1922	60,000		37,874,117	1,884,170
18	Lake Basin, *Stillwater*	1924	300	1,500	444,359	19,620
19	Pondera, Pondera, *Teton*	1927	1,600		5,663,417	301,273
20	Sweetgrass Hills, *Liberty, Toole*	1929	500	8,000	100,962	8,289
	WYOMING					
1	Alkali Butte, *Fremont*	1928	40	300	5,670	0
2	Allen Lake, *Carbon*	1933		200		
3	Ant Hills, *Niobrara*	1928	40		8,719	0
4	Badger Basin, *Park*	1931	300		370,552	87,351
5	Baxter Basin (South), *Sweetwater*					
6	Frontier	1922		7,467		
7	Dakota	1922		4,310		
8	Baxter Basin (North), *Sweetwater*					
9	Dakota	1926		1,280		
10	Sundance	1928		2,280		

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Wells produce large quantities of CO_2 with the oil—shut in.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft. — To End of 1940	Total Gas Production — During 1940	Number of Oil and/or Gas Wells — Completed to End of 1940	During 1940 — Completed	During 1940 — Abandoned	End of 1940 — Temporarily Shut Down	End of 1940 — Producing Oil[c]	End of 1940 — Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells — Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In. — Initial	Avg. at End of 1940	Character of Oil — Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
							COLORADO							
1	6,806	549	6				1	1		1	600	75	38.5	0.1
2			55				11			11			38.6	0.2
3			1,208	2	1		105			105			31.0	0.1
4			16				6			6			37.0	0.1
5	7,258	730	16					6			12	[3]		
6			8				1			1			42.0	0.1
7			23				12			12			41.0	0.1
8	185,277	23,940	14	3			3		3		850	y[4]	36.9	0.1
9			40				30			30			37.0	0.1
10	645[2]	0	8			5					12	Shut in		
11			89	8	7	1	8			8			43.0	0.1
12	2,628	970	4					3			725	650		
13			17				9			9			35.0	0.1
14			5			5							50.0	0.1
15			32				11			11			37.4	0.1
16			20				9			9			40.0	0.1
17			4	1	1		2		2				46.0	0.1
							MONTANA							
1			30	0	0	0	17						34	1.20
2														
3														
4														
5			330	0	0	0	104							
6													49	0.22
7													49	0.48
8														
9														
10														
11			663	94	12	1	521	78					41	1.02
12			16	1	0	0	7						51	0.03
13														
14														
15			33	0	0	0	22						43	0.14
16														
17			2,561	70	17	0	1,000	187					34	1.2
18			40	0	0	0	2	0					44.1	0.1
19			187	1	0	0	153	0					37	1.9
20			32	0	0	0	9						36	0.83
							WYOMING							
1			3	0	0	3	0	0			y	y	37	
2	8,324	66	7	0	0	0	0	4			920	440		
3			3	0	0	0	0	0					35	
4											y	y	48	
5			5	0	0	2	3	0	3					
6		4,275	26	0	0	0	0	25			800			
7	29,707													
8		1,520	8	0	1	0	0	6			815			
9														
10														

[2] Contains 7.9 per cent helium, balance nitrogen and carbon dioxide.
[3] Operating under vacuum.
[4] Gas is produced from sand lenses. Initial pressures range from 661 to 1315 lb. per sq. inch.

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
	COLORADO									
1	Hygiene	CreU	S	20	2,920	2,940	20	A	Lakota (CreL)	4,031
2	Pierre	CreU	H		2,000			MF		
3	Pierre	CreU	H		2,200			TS	Fountain (Pen)	1,875
4	Muddy-Dakota	CreU	S	12	4,535	4,560	25	A	Sundance (Jur)	5,206
	Sundance	Jur	S	16	5,063	5,202	139			
5	Benton	CreU	H		1,600			D	Fountain (Pen)	2,500
6	Muddy	CreU	S	9	6,645	6,680	35	A	Morrison (Jur)	7,040
7	Dakota	CreU	S	18 [5]	3,860	3,880	20	D	Sundance (Jur)	4,490
	Sundance	Jur	S	14						
8	Wasatch	Eoc	S	y	Sand lenses			D	Mesa Verde (CreU)	7,577
9	Sundance	Jur	S	9	3,295	3,315	20	D	Sundance (Jur)	3,447
10	Santa Rosa (?)	Tri	S	19	960	1,004	50	D	Fountain (Pen)	2,010
11	Mancos	CreU	H		600			A	Pennsylvanian	7,173
12	Dakota	CreU	S	15	2,200	2,230	30	D	Sundance (Jur)	3,110
13	Mancos	CreU	H		2,600			A	Gneiss[6]	5,310
14	Muddy-Dakota	CreU	S	14	5,110	5,215	90	AF	Morrison (Jur)	5,258
15	Muddy-Dakota	CreU	S	12	4,480	4,500	20	A	Sundance (Jur)	4,992
16	Dakota	CreU	S	y	1,120	1,140	20	A	Dakota (?)	1,350(?)
17	Morrison	CreU	S		6,550	6,675	125	D	Sundance (Jur)	6,918
	MONTANA									
1	Vanalta	CreL	S, SH	14	2,470	2,500	15	MC	Madison (Mis)	2,645
2	Colorado	CreU	SH		750	720	50	D	Mississippian(?)	3,180
3	Eagle	CreU	S	15	975	1,045	100	D	Madison	4,700
4	Eagle	CreU	S	17	1,200	1,272	100	A	Eagle	1,276
5										
6	First Cat Creek	CreU	S	15	1,200	1,245	50	AF		
7	Second Cat Creek	CreL	S	15	1,400	1,440	40	AF	Madison	1,964
8	Judith River	CreU	S	15	830	900	70	A		
9	Eagle	CreU	SH	y	1,460		60	A		
10	Madison	Mis	L	y	6,750	6,800	50	A	Devonian	8,186
11	Cut Bank	Jur	S	14	2,800	2,835	30	MC	Madison	3,160
12										
13	Frontier	CreU	S	18	4,400	4,450	50	AF		
14	Cloverly	CreL	S	y	5,500	5,525	25	AF	Tensleep	6,887
15										
16	Frontier	CreU	S	y	700	730	20	MF(?)	Tensleep	4,120
17	Ellis-Madison Contact	Jur-Mis	L	y	1,450	1,470	10	?	Pre-Cambrian	4,710
18	Eagle, Frontier, Dakota	CreU, L	S	y	1,200	1,320	100	D	Madison	6,002
19	Madison	Mis	L	y	1,975	1,990		T	Madison	2,354
20	Upper Ellis	Jur	S	y	1,400	1,420		D	Madison	2,205
	WYOMING									
1	Morrison	Jur	S	Por	4,570	4,600	30	A	Chugwater	5,460
2	Sundance	Jur	S	Por	2,100	2,175	40	A	Chugwater	4,083
3	Dakota	CreU	S	Por	3,951	3,957	6	A	Lakota	4,257
4	Frontier	CreU	S	Por	8,250	8,500	49	A		
5										
6	Frontier	CreU	S	Por	2,200	2,400	16	AF	Nugget	3,822
7	Dakota	CreU	S	Por	3,000	3,500	50	AF		
8										
9	Dakota	CreU	S	Por	2,950	3,100	20	AF	Chugwater	4,200
10	Sundance	Jur	S	Por	3,350	3,400	15	AF		

[5] Figures from recovery indicate 20 per cent.
[6] Oldest sedimentary formation tested Thaynes (Triassic).

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
11	Beaver Creek, *Fremont*	1937		640		
12	Big Muddy, *Converse*	1915				
13	Shannon	1916				
14	Wall Creek	1916		2,000	26,595,914	432,727
15	Dakota	1922				
	Big Sand Draw, *Fremont*					
16	Wall Creek	1917		1,200		
17	Lakota	1930		300		
18	Billy Creek, *Johnson*	1921		1,200		
19	Black Mountain, *Hot Springs*	1925	300		235,654	0
20	Bolton Creek, *Natrona*	1920			27,102	0
21	Sundance	1920	50			
22	Embar	1920	50			
23	Boone Dome, *Natrona*	1920		300		
24	Bunker Hill, *Carbon*	1936		480		
25	Byron Dome, *Big Horn*	1906				
26	Frontier	1922		500		
27	Sundance	1929	40			
28	Embar-Tensleep	1932	2,950		4,733,541	890,945
29	Cole Creek, *Natrona*	1937	900		205,313	157,351
30	Dallas-Derby, *Fremont*	1883	350		2,939,642	162,155
31	Dewey Dome, *Weston*	1938	40		21,186	2,182
	Dutton Creek, *Carbon*					
32	Shannon	1926		800		
33	Muddy	1926	150		267,444	17,936
34	East Allen Lake, *Carbon*	1936		410	Included with Allen Lake	
35	East Lance Creek, *Niobrara*	1918	400	150	137,*xxx*	*x*
36	Eight Mile Lake, *Carbon*	1923		250		
37	Elk Basin, *Park*	1915				
38	Frontier		580		11,179,254	207,628
39	Dakota			1,200		
40	Enos Creek, *Hot Springs*	1923	Field abd.			
41	Ferris, *Carbon*	1918	200	200	481,686	0
42	West Ferris (East Mahoney), *Carbon*	1940			14,423	14,423
43	Fourbear, *Park*	1928	500			
44	Frannie, *Park*	1928				
45	Tensleep		500		4,502,564	933,487
46	Garland, *Big Horn-Park*	1930			4,139,051	1,076,021
47	Frontier		40	1,000		
48	Dakota			1,200		
49	Embar-Tensleep		160	1,650		
50	Madison		2,000	500		
51	Golden Eagle, *Hot Springs*	1919		120	Field abd.	
52	Gooseberry, *Park*	1936	500		0	Shut in
53	Grass Creek, *Hot Springs*	1914			28,518,202	709,108
54	Frontier		1,400			
55	Embar-Tensleep		2,000			
56	Greybull, *Big Horn*	1907	640		346,730	0
57	Hamilton, *Hot Springs*	1913	2,000		5,239,905	183,806
58	Hidden Dome, *Washaki*	1933	50	640	308,614	26,279
59	Iron Creek, *Natrona*	1922	80	80	18,921	4,871
60	La Barge, *Lincoln-Sublette*	1923	950		6,557,116	534,915
61	Lake Creek, *Hot Springs*	1925	100		Shut in	
62	Lance Creek, *Niobrara*	1918			32,084,272	9,324,408
63	Dakota		1,000	3,500		
64	Sundance		1,700			
65	Minnelusa		15,000			
66	Lander (Hudson), *Fremont*	1914	340		2,121,455	87,717
67	Little Buffalo Basin, *Park*	1914		4,800		
68	Little Grass Creek, *Hot Springs*			300		
69	Little Polecat, *Park*	1918		500		
70	Lost Soldier, *Sweetwater*	1915			20,617,566	842,815
71	Frontier		160			
72	Dakota-Lakota		450			
73	Sundance		160			
74	Tensleep		160			

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Avg. at End of 1940	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
11	0	0	1	0	0	1	0	0			2,500	2,500		
12														
13														
14			174	0	0	0	149	0		149			33.5	
15														
16			13	1	0	0	0	13			1,300	680		
17	58,690	3,995									1,860	0		
18	3,264	250	10	0	0	0	0	3			1,150	350		
19			6	0	0	6	0	0					19	
20			14	0	0	0	0	0					22	
21														
22														
23	4,072	0	4	0	0	0	0	0			750	180		
24	1,792	90	5	0	0	0	0	2			500	x		
25														
26														
27														
28			19	0	0	0	14	0		14			20	
29			11	9	0	2	8	0		8			32.7	
30			72	0	0	0	42	0		42			Dallas 23.2 Derby 22.3	
31			5	0	1	0	1	0		1			31	
32														
33			8	0	0	0	3	5		3			33.6	
34			2	0	0	0	0	2			1,050	950		
35			3	0	0	1	1	0			950			
36	49,983	639	4	0	0	0	0	1			1,724	550		
37														
38			153	0	0	0	144	0		144			43	
39			6	0	0	0	0	5			925	440		
40			3	0	0	0	0	0			750			
41			25	0	0	11	0	0					36.3	
42			1	1	0	0	1	0		1			42	
43			1	0	0	1	0	0					15	
44														
45			20	2	1	0	14	0		14			27.7	
46			83	4	0	0	14	10		14			22	
47											x	x		
48											745	145		
49											1,470	1,260		
50											1,600	1,260		
51			3	0	0	0	0	0			1,175	Exh.		
52			3	0	0	1	0	0					22	
53			331	0	0	0	330	0		330			Light 43	
54													Heavy 19–24.7	
55														
56			14	0	0	3	0	0		3			44.3	
57			36	0	0	0	33	0		33			Embar 25.6 Tensleep 16.7	
58	Gas exhausted		30	0	0	0	15	0		15	725	Exh.	40	
59	Gas exhausted		5	0	0	0	1	0		1	200	Exh.	32	
60			145	17	3	0	106	1		106			32	
61			3	0	0	1	0	0		1			26	
62			281	53	3	0	133	12		133			43.6	
63														
64														
65														
66			36	0	0	0	11	0		11			23.3	
67	20,966	17,975	13	0	0	0	0	11			690	385		
68	x	x	2	0	0	0	0	2			1,140	400		
69	11,401	114	1	0	0	0	0	1			1,375	1,080		
70			133	8	0	0	76	10	2	74			Light 32	
71													Heavy 28.8	
72														
73														
74														

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
11	Lakota	CreU	S	Por	8,244	8,288	44	A	Sundance	8,920
12										
13	Shannon	CreU	S	Por	1,200	1,250	65	A		
14	Wall Creek	CreU	S	Por	3,260	3,400	100	A	Madison	6,597
15	Dakota	CreU	S	Por	4,600	4,700	15	A		
16	Wall Creek	CreU	S	Por	2,300	2,800	150	A	Sundance	5,345
17	Lakota	CreL	S	Por	4,300	4,350	40	A		
18	Wall Creek	CreU	SH	Por	3,200	3,250	30	A	Big Horn lime	7,775
19	Embar-Tensleep	Per, Pen	LS		2,900	3,350	135	A	Madison	3,832
20										
21	Sundance	Jur	S	Por	1,015	1,120	10	AF	Amsden	2,867
22	Embar	Per	L	Cav	2,025	2,050	15	AF		
23	Shannon	CreU	S	Por	2,150	2,200	70	A	Niobrara	5,200
24	Shannon	CreU	S	Por	1,224	1,480	250	A	Sundance	67
25										
26	Frontier	CreU	S	Por	2,400	2,500	30	A		
27	Sundance	Jur	S	Por	4,205	4,209	4	A	Amsden	6,700
28	Embar-Tensleep	Per, Pen	LS	Cav Por	5,300	5,700	130	A		
29	Lakota	CreL	S	Por		8,019		A	Sundance	8,707
30	Embar-Tensleep	Per, Pen	LS	Cav Por	700	1,200	150	A	Tensleep	1,400
31	Leo sand	Pen	S	Por	2,294	2,349	40	A	Minnelusa	2,505
32	Shannon	CreU	S	Por	1,600	1,700	40	A	Sundance	5,448
33	Muddy	CreU	S	Por	4,850	4,900	30	A		
34	Sundance	Jur	S	Por	2,000	2,088	48	A	Sundance	2,180
35	Dakota	CreU	S	Por	3,808	4,008	95	A	Madison	6,434
36	Dakota	CreU	S	Por	3,400	3,500	50	A	Chugwater	4,560
37										
38	Frontier	CreU	S	Por	1,000	1,200	40	AF	Morrison	3,223
39	Dakota	CreU	S	Por	2,400	2,500	55	AF		
40	Frontier	CreU	S	Por	2,600	2,850	40	A	Dakota	3,992
41	Mowry-Dakota	CreU	S	Por	1,600	1,650	25	A	Embar	4,600
42	Tensleep	Pen	S	Por	4,272	4,293	21	A	Tensleep	4,315
43	Tensleep	Pen	S	Por	3,270	3,350	60	A	Tensleep	3,350
44										
45	Tensleep	Pen	S	Por	2,770	3,530	100	AF	Madison	3.013
46										
47	Frontier	CreU	S	Por	700	900	35	AF		
48	Dakota	CreU	S	Por	1,500	1,600	50	AF	Cambrian	4,750
49	Embar-Tensleep	Per, Pen	LS	Cav Por	3,000	4,275	100	A		
50	Madison	Mis	L	Por Cav	3,600	4,726	300	A		
51	Mesaverde	CreU	S	Por	2,250	3,000	50	A	Cody	4,019
52	Embar-Tensleep	Per, Pen	LS	Cav Por	5,669	6,049	50	A	Tensleep	6,076
53										
54	Frontier	CreU	S	Por	800	1,200	250	A	Amsden	4,335
55	Embar-Tensleep	Per, Pen	LS	Cav Por	3,600	4,000	200	A		
56	Greybull	CreU	S	Por	1,000	1,050	20	AF	Tensleep	2,950
57	Embar-Tensleep	Per, Pen	LS	Cav Por	2,700	3,332	130	A	Tensleep	2,886
58	Frontier	CreU	S	Por	1,200	1,600	15	A	Greybull	2,785
59	Dakota	CreU	S	Por	650	820	25	A	Sundance	1,633
60	Wasatch	Eoc	S	Por	650	1,000	150	AF	Hilliard	6,200
61	Embar	Per	L	Cav	3,730	3,760	30	A	Tensleep	3,830
62										
63	Dakota	CreU	S	Por	2,820	3,665	65	A		
64	Sundance	Jur	S	Por	3,500	4,100	65	A	Granite	6,434
65	Leo	Pen	S	Por	4,900	5,630	60	A		
66	Embar-Tensleep	Per, Pen	LS	Cav Por	1,300	2,750	185	A	Tensleep	2,190
67	Frontier	CreU	S	Por	1,200	1,500	100	A	Mowry	1,670
68	Frontier	CreU	S	Por	2,665	2,901		A	Frontier	2,901
69	Frontier	CreU	S	Por	3,900	4,100	15	A	Cloverly	5,660
70										
71	Frontier	CreU	S	Por	175	900	200	AF		
72	Dakota-Lakota	Cre	S	Por	1,375	2,100	80	AF	Tensleep	4,087
73	Sundance	Jur	S	Por	1,875	2,100	300	AF		
74	Tensleep	Pen	S	Por	3,900	4,097	50	AF		

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
75	Mahoney Dome, *Carbon*	1930			295,064	159,656
76	Dakota			1,400		
77	Sundance			1,660		
78	Tensleep		250			
79	Maverick Springs, *Fremont*	1916	1,400		12,366	12,366
80	Medicine Bow, *Carbon*	1935	800	320	3,544,680	274,329
81	Midway, *Natrona*	1930	200		175,886	723
82	Mule Creek (East), *Niobrara*	1919			1,203,240	8,143
83	Mule Creek (West), *Niobrara*					
84	Muskrat, *Fremont*			500		
85	Notches, *Natrona*	1923	400		167,114	0
86	Oil Springs, *Carbon*	1938		160		
87	Oregon Basin, *Park*	1927				
88	Dakota			1,300		
89	Embar-Tensleep		10,000		13,682,236	2,031,909
90	Osage, *Weston*	1920	10,000		4,570,118	213,300
91	Pilot Butte, *Fremont*	1916	250	400	564,272	2,410
92	Quealy, *Albany*	1934	320		1,399,059	171,827
93	Rex Lake, *Albany*	1923	200		228,199	173
94	Rock Creek, *Carbon*	1918			19,812,832	919,284
95	Dakota		1,300			
96	Sundance		500			
97	Salt Creek, *Natrona*	1908			293,563,715	5,206,284
98	1st Wall Creek		4,350			
99	2nd Wall Creek		21,450			
100	Lakota		2,030			
101	Sundance		660			
102	Tensleep		640			
103	Shannon, *Natrona*	1889	200		55,441	0
104	Shoshone, *Park*	1929	540		38,089	14,493
105	Simpson Ridge, *Carbon*	1924			162,485	Shut in
106	South Casper Creek, *Natrona*, and Poison Spider, *Natrona*	1920	240		3,558,281	117,771
107	Spindle top, *Natrona*	1928	80		22,507	4,192
108	Spring Valley, *Uinta*	1903	400		101,593	0
109	Teapot, *Natrona* (outside Naval Reserve)	1927			105,601	5,841
110	Wall Creek					
111	Shale					
112	Torchlight, *Big Horn*	1915	600		254,709	Shut in
113	Warm Springs, *Hot Springs*	1917	160		367,755	26,225
114	Waugh Dome, *Hot Springs*	1935	100		210,069	
115	Wertz, *Carbon*	1921			2,245,612	988,486
116	Frontier			100		
117	Dakota			500		
118	Lakota			500		
119	Sundance			200		
120	Tensleep		600			

UTAH

Line Number	Field, *County*	Year of Discovery	Oil	Gas[b]	To End of 1940	During 1940
1	Ashley Valley, *Uinta*	1926		240		
2	Cisco, *Grand*	1925		2,000		
3	Clay Basin, *Daggett*	1928		2,800		
4	Farnham, *Carbon*	1924		600		
5	San Juan, *San Juan*	1910	160		14,*xxx*	50
6	Virgin, *Washington*	1908	450		178,525	3,275

TABLE I.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Character of Oil	
				During 1940		End of 1940			Number of Wells					
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
75	58,026	300	18	1	0	0	4	9		4			32	
76											1,060	150		
77											1,170	150		
78														
79			32	0	0	27	2	0		2			22	
80	4,938	*y*	14	0	0	0	10	2	10		1,900	*y*	56.9	
81			3	0	0	2	0	0		2			32.5	
82			84	0	0	0	42	0	0	42			32	
83														
84	13,992	3,100	6	1	0	0	0	5			2,175	*y*		
85			5	0	0	2	0	0		2			16	
86			2	0	0	0	0	2			1,200	*x*		
87			46	3	0	0	38	5						
88	2,553	250												
89														
90			523	11	16		280			280			41.6	
91	Shut in		17	0	0	2	5	0		5	800	S.I.	42	
92			19	0	0	0	17	0		17			32.8	
93			4	0	0	0	3	0		3			35	
94			73	1	0		42	0		42			37	
95														
96														
97			1,999	1	0	0	1,880	0		1,880				
98													36	
99													36	
100													38	
101													35	
102													35	
103			18	Field abd.									24	
104			3	0	0	0	1	0		1			21.1	
105			13	0	1	11	0	0					20.4	
106	16,892	Exh.	*x*	0	0	0	33	0		33			Sundance 21	
													Tensleep 15.3	
107			6	0	0	0	4	0		4			22	
108			30	0	0	2	0	0		0			48.3	
109			2	0	0	0	2	0		2			35.2	
110														
111														
112			30	0	0	*x*	0	0		0			45.6	
113			46	0	0	0	19	0		19			21	
114			2	0	0	0	0	0		0	Field abd.		27.2	
115	63,082	417	17	1	0	0	4	7	4					
116														
117														
118														
119														
120														

UTAH

Line Number	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil	Producing Gas	Flowing	Artificial Lift	Initial	Avg. at End of 1940	Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
1	22,000	356	5	0	0	0	0	2			580	190		
2	3,128	[7]	17	0	0	1	0	0			750	325[10]		
3	138,923	4,308[9]	7	1	0	0	0	6			2,250	*y*		
4	8,870	679[8]	2	0	0	0	0	1			750	290		
5			116[9]	0	0	0	1	0		1			39	0.1
6			132	0	0	0	20	0		20			34	0.83

[7] Field abandoned 1937 and all wells plugged except one.
[8] Carbon dioxide gas.
[9] Includes assessment holes 500 ft. deep.
[10] Pressure at time of abandonment.

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
75										
76	Dakota	CreU	S	Por	2,170	2,300	30	A		
77	Sundance	Jur	S	Por	2,600	2,760	110	A	Tensleep	4,690
78	Tensleep	Pen	S	Por	4,600	4,760	160	A		
79	Embar	Per	L	Cav	1,450	1,700	50	A	Tensleep	2,094
80	Sundance	Jur	S	Por	5,200	5,430	140	A	Chugwater	5,910
81	Frontier-Muddy	CreU	S	Por	5,200	5,250	60	A	Chugwater	6,689
82										
	Lakota	CreL	S	Por	1,500	1,550	25	A	Minnelusa	3,185
	Minnelusa	Pen	S	Por	3,170	3,180	10	A		
83	Dakota-Lakota	Cre	S	Por	170	350	30	A	Madison	3,047
	Minnelusa	Pen	H	Fis	2,800	2,830	10	A		
84	Frontier	CreU	S	Por	4,270	4,340	150	AF	Madison	8,112
	Dakota	CreU	S	Por	5,306	5,320	60	AF		
85	Tensleep	Pen	S	Por	2,800	2,850	40	A	Tensleep	2,830
86	Sundance	Jur	S	Por	2,225	2,353	90	A	Tensleep	2,353
87										
88	Dakota	CreU	S	Por	1,500	1,550	45	AF		
89	Embar-Tensleep	Per Pen	LS	Cav Por	3,500	3,900	150	AF	Madison	4,160
90	Newcastle	CreU	S	Por	220	2,154	10	ML	Minnelusa	2,235
91	Niobrara	CreU	H	Fis	800	1,000		A	Sundance	4,630
92	Muddy-Dakota	CreU	S	Por	3,260	3,320	60	A	Sundance	4,207
93	Dakota	CreU	S	Por	3,800	3,900	50	A	Lakota	3,930
94										
95	Dakota	CreU	S	Por	2,600	3,300	110	A	Embar	5,627
96	Sundance	Jur	S	Por	3,150	3,250	100	A		
97										
98	1st Wall Creek	CreU	S	Por	1,000	1,100	110	AF		
99	2nd Wall Creek	CreU	S	Por	1,535	2,575	65	AF		
100	Lakota	CreL	S	Por	2,300	2,350	20	AF	Granite	5,400
101	Sundance	Jur	S	Por	2,750	2,875	70	AF		
102	Tensleep	Pen	S	Por	3,970	3,980	190	AF		
103	Shannon	CreU	S	Por	800	900	75	MUP	Shannon	*y*
104	Embar	Per	L	Cav	4,300	5,000	24	A	Tensleep	4,775
105	Quealy	CreU	S	Por	625	675	40	A	Steele shale	6,931
106	Tensleep	Pen	S	Por	2,600	2,700	150	A	Tensleep	2,700
	Sundance	Jur	S	Por	1,400	1,425	35	A	Granite	4,119
107	Sundance	Jur	S	Por	1,100	1,125	25	A	Tensleep	2,705
108	Aspen	CreU	H	Fis	400	900	*x*	MC	Bear River	2,065
109										
110	Wall Creek	CreU	S	Por	2,900	2,950	40	AF	Frontier	3,140
111	Shale	CreU	H	Fis	1,200	1,600	*x*	AF		
112	Mowry	CreU	SH	Por	400	600	50	A	Madison	4,165
113	Embar	Per	L	Cav	700	800	50	A	Tensleep	1,590
114	Embar	Per	L	Cav	3,775	3,807	35	A	Tensleep	4,246
115										
116	Frontier	CreU	S	Por	2,210	2,260	50	A		
117	Dakota	CreU	S	Por	3,500	3,550	50	A		
118	Lakota	CreL	S	Por	3,700	3,750	40	A	Tensleep	5,883
119	Sundance	Jur	S	Por	4,100	4,120	20	A		
120	Tensleep	Pen	S	Por	5,859	5,886	27	A		
	UTAH									
1	Morrison	Jur	S	*y*	1,665	1,675	10	AF	Nugget-Jur	2,720
2	Dakota / Morrison	CreU / Jur	S	*y*	2,056	2,174	15	D	Kayenta-Jur	3,045
3	Dakota	CreU	S	18	5,700	5,800	40	D	Sundance-Jur	6,790
4	Coconino	Per	S	*y*	3,093	3,114	21	AF	Kaibab-Per	3,235
5	Goodridge	Pen	S	*y*	194	200	6	S	Hermosa-Pen	3,663
6	Kaibab-Moenkopi Contact or Upper Kaibab	Tri	L	*y*	663[11]	665	2	MC	Coconino-Supai-Per	2,195

[11] 515 ft. to 815 ft. depending on position on monoclinal structure.

found in Wasatch sand at 5014 to 5032 ft., from which oil flowed from the well at the rate of 60 bbl. an hour, with an estimated gas volume of 3,000,000 cu. ft. per day. The oil is green in color and has a gravity on the A.P.I. scale of 37.4°. It carries an exceptionally high amount of wax and congeals at 50°F.

Other wells drilled at Powder Wash up to the end of 1937, when operations were suspended, include No. 1 Hal Stewart, completed at 3087 ft. for 800 bbl. of oil per day, and No. 1 Donnell, completed at 3102 ft. after plugging back from 3878 ft., for an open flow of 4,000,000 cu. ft. of gas with a pressure of 1030 lb. per sq. inch.

Montana

Oil development in Montana in 1940 was confined largely to the drilling of offset locations in proved fields to maintain production, and to the fulfillment of lease obligations. The northern Montana fields, Cut Bank in Glacier County, and Kevin-Sunburst in Toole County, were especially active. The Cut Bank field was extended about one mile southwest by the completion of A. B. Cobb's No. 1 Tribal 187, C.SE.NW. of sec. 19-32N-5W. This well had the Cut Bank sand from 2810 to 2820 ft., and was completed at 2827 ft. for 95 bbl. of oil per day on 10-day pumping test.

The productive gas area was extended on the east side of the field along the Glacier-Toole County line by Glacier Production Company's No. 1 Dahlquist in sec. 12-34N-5W., and No. 1 Delaney in sec. 36-34N-5W.

Development of Montana gas fields continued through the 1940 drilling season. In the Bowes field, Blaine County, three completed gas wells added 32,100,000 cu. ft. of gas per day to the field's potential. Nine producing gas wells were completed in the Cedar Creek field on the Baker-Glendive anticline, which added 9,562,000 cu. ft. of gas daily to that field's potential.

The Devon gas field, 35 miles east of Shelby, was tied into the Montana Dakota Utilities Company's trunk gas line from the Border fields in northern Montana to Great Falls. Two new wells were completed in the field during the summer, which added 5,600,000 cu. ft. of gas per day to the field's potential, and additional development is scheduled for 1941. This field is controlled by C. L. Smith, of Denver, Colo., who discovered the field in 1933 with the completion of his No. 1 Mowat on the SW.SW.SE. of sec. 7-33N-2E.

Two completions at Whitlash, on the Canadian border, gave that field an added reserve of 10,150,000 cu. ft. Gas from Whitlash goes to Great Falls.

At Bowdoin, Phillips County, the Montana Dakota Utilities Company's 1940 drilling program resulted in the completion of 14 wells with a combined gauge of 9,980,000 cu. ft. of gas. These wells have small initial capacities but they decline very slowly and produce a large volume of gas over a long period of years. The wells are started with a spudder and drilled to about 100 ft., then surface pipe is set and cemented. They stand idle thereafter until the company's rotary equipment is available for drilling to completion.

Frannie Field, Carbon County.—The Frannie field, Park County, Wyoming, was extended into Montana in September 1940 by the Continental Oil Co. with the completion of No. 1 Prigge, SE.SE.SE. of sec. 33-9S-25E. This well is about ¼ mile in advance of the production on the Wyoming side of the line. It had the top of the Embar lime at 3490 ft., top of the Tensleep sand at 3523 ft. and was drilled into the Tensleep to a total depth of 356½ ft., where it was completed for an initial production of 124 bbl. of oil a day, pumping, after treatment with a total of 2000 gal. of acid.

Wyoming

Cole Creek Field, Natrona County.—The development of the Cole Creek field was

started in May 1940 by General Petroleum Corporation, with the completion of No. 1-21-G, NW.NW.NW. of sec. 21-35N-77W., in Shannon sand at 4530 to 4570 ft. after plugging back from a total depth of 8050 ft., where it tested the Morrison sand with negative results. In the Shannon sand, the well swabbed 400 bbl. of oil and pumped 350 bbl. per day on an 8-day pumping test.

In the remaining seven months of 1940, General Petroleum Corporation drilled eight wells in the field and recompleted one old well in Shannon sand, developing a potential production of 1880 bbl. of oil per day. The field was connected to the company's refinery (White Eagle Division) at East Casper by 13 miles of 4-in. pipe, through which an average of 720 bbl. of oil a day was moved during the closing months of the year.

Although the presence of oil in Shannon sand at Cole Creek was known prior to 1940, the first well in that sand began producing in May 1940, therefore the field may properly be classed as a 1940 discovery.

Lost Soldier Basin Fields, Sweetwater and Carbon Counties.—The results of its 1939 development program in the Lost Soldier and Wertz fields encouraged the Sinclair Wyoming Oil Co. to a more intensive campaign in 1940, with the result that oil was discovered in Tensleep sand in a well drilled in the West Ferris field, and deeper pays in the Tensleep were discovered in old wells in the Mahoney field and in the Lost Soldier field.

In 1940, potential production of Wertz, Lost Soldier, Mahoney and Ferris fields was more than 20,000 bbl. per day, and late in the year Sinclair Wyoming Oil Co. began moving some of this oil to Sinclair refining centers in the middle west. To accomplish this, during the past summer Sinclair laid 27½ miles of 8-in. pipe from its Casper pump station to a junction with the Stanolind's Teapot-Freeman line at Clayton tank farm, Missouri. By this arrangement, the process has been reversed and oil is now moved northward from the Lost Soldier Basin fields to Casper and thence east to Freeman, Mo. Oil from Sinclair connections at Salt Creek formerly was moved to Parco via Casper. Under the new arrangement, the Salt Creek oil now goes east with the Lost Soldier Basin oil. The Sinclair interests also have a trunk pipe line southward from Lost Soldier to their Parco refinery, and the Parco refinery is further served by the line of the Utah Oil Refining Co. from Fort Laramie, Wyo., to Salt Lake City. Through this line, the Parco refinery receives oil from Lance Creek, Quealy and Big Medicine Bow.

Lost Soldier Field, Sweetwater County.—Deeper drilling at Lost Soldier field resulted in the discovery, in October 1940, of a pay in the basal Tensleep sand. The well used for this test was No. 75-A, approximately NW.SW.NW. of sec. 11-26N-90W. This is the discovery well of the Tensleep at Lost Soldier and was completed in June 1930, in sand at 3942 to 3962 ft. for an initial production of 1800 bbl. of oil a day of 34.5° A.P.I. gravity. In December of that year, it was deepened to 4009 ft., still in Tensleep sand, where it started off at the rate of 2500 bbl. of oil a day with a slight increase in the gravity of the oil. Early in October 1940, this well had reached basal Tensleep sand, where it was completed at 4244 ft. for an initial production of 1420 bbl. On gas lift, it made 2157 bbl. of oil in 24 hr. Two old Tensleep wells were then deepened to the basal sand and recompleted, one for 840 bbl. a day, the other for 320 bbl. in 20 hours.

Wertz Dome Field, Carbon County.—The Wertz dome field, in which oil was discovered in upper Tensleep sand in 1936, became a major oil field in 1939 through the discovery of oil in the lower Tensleep. No additional discoveries have been made in the field since 1939, but during 1940 the development program had increased the potential of the field materially, and it is expected that the 1941 drilling campaign

will move this field nearly to first place in the Wyoming production column before the end of this year.

Following the discovery of oil in lower Tensleep in 1936, two wells were completed at Wertz in 1937, one of which, No. 11-A on the SE.NW.NW. of sec. 7, was deepened in August 1939 from 5987 to 6238 ft., where it was credited with an initial production of 4622 bbl. Other completions in 1939, following the deepening operations and the drilling of No. 13 Wertz, resulted in developing in this field, total new production, out of four wells, of 19,675 barrels.

Only one well was drilled in the Wertz field in 1940, but it gave an excellent account of itself and extended the field about ¼ mile east, but by late December 1940 the 1941 drilling campaign was under way, with four wells drilling and rigs up for two additional wells.

Mahoney Dome, Carbon County.—Deeper drilling on Mahoney dome by Sinclair Wyoming Oil Co. resulted in the discovery of a deeper pay zone within the Tensleep formation. The well used for this test was No. 3-F Mahoney on the C.SE.NW. of sec. 34-26N-88W., completed in November 1938 in Tensleep sand at 4295 to 4486 ft., for an initial production of 172 bbl. of oil per day. In November 1940, this old well was deepened from 4486 to 4505 ft. and recompleted after a 500-quart shot of nitroglycerin for an initial production of 511 bbl. of oil in 15½ hr. At the close of the year 1940, one old well was in the process of being deepened into the Tensleep pay and one new well was drilling.

East Mahoney (West Ferris), Carbon County.—A deeper pay was discovered in the East Mahoney (West Ferris) field last March, adding the fourth field in the Basin in which Tensleep oil is found. The new well is No. 4-E, on the C.SE.SW. of sec. 29-26N-87W. It had the top of the Tensleep pay at 4272 ft., but encountered water in the sand at 4315 ft. and was plugged back to 4293 ft., from which depth it swabbed 200 bbl. of oil per day and flowed 50 bbl. a day through the tubing. The oil has a gravity of 42° A.P.I.

Vermillion Creek, Sweetwater County.—Gas was discovered late in December on Vermillion Creek, southern Sweetwater County, by Vermillion Oil Company's No. 2 Amelia Horricks, SW.SW.SW. of sec. 7-12N-99W. The new well found its gas production in sand lenses in the Wasatch at 3474 to 3496 ft. and 3500 to 3530 ft., where it gauged 12,000,000 cu. ft. of gas under a natural pressure of 1200 lb. per sq. in. It has not yet been determined whether the discovery constitutes an extension to the Hiawatha field or is a separate structure. In any event, it is a mile ahead of production and opens some new prospecting territory.

La Barge Field, Sublette County.—The LaBarge field was extended about one mile north during the 1940 drilling season, with the completion of 15 wells in sec. 27 and sec. 28-26N-113W. The best of the completions was Marvel Oil Company's No. 1-H Government, CEL.NE.SE. of sec. 28, which started at the rate of 285 bbl. of oil per day, flowing from sands at 923 to 974 ft. and 994 to 1065 ft. The south offset, drilled by the same company, flowed 300 bbl. of oil per day, and the east offset, drilled by The Texas Company, averaged 188 bbl. per day on 10-day test. These were the record wells. Other completions were good, considering the shallow depth, the smallest of which, an edge well, made 4 bbl. per day. As a result of these operations, about 160 acres was added to the productive area of the field and the gross production of the field increased rapidly during the last half of the year.

Lance Creek Field, Niobrara County.—The 1940 drilling program of the unit operators at Lance Creek was confined to the drilling of inside locations within the unit area. In addition to its operations within the unit, Continental drilled a large number of wells on the acreage of its

subsidiary, Buck Creek Oil Co., in secs. 34 and 35 in T. 36 N., R. 65 W. The Ohio Oil Co. drilled two wells in sec. 36-35N-65W., on the eastern edge of the field, well outside of the unit, and extended the productive area of the field about ½ mile north and east. Both were Sundance sand producers.

The southern edge of the field has not been limited by dry holes but completions of the Minnelusa Oil Co. on its H. & M.-5 lease and for its joint account with MacKinnie Oil and Drilling Co. on the Thompson lease, found the Leo sand running low and probably will not venture any farther south. Two of this series of wells were excellent producers. No. 5 Thompson is being used as a gas-input well.

The western edge of the field was defined by two wells, Argo Oil Corporation's No. 1 Ong, drilled by the unit operators on the SE.SE.SW. of sec. 31-36N-65W., and Holly Development Company-A. B. Cobb's No. 5 Novick, NE.NE.NW. of sec. 6-35N-65W.

The Ong well entered a fault at 4488 ft. and immediately below that depth cores were taken. The bedding was almost vertical in the cores recovered, the material was slightly brecciated and compacted, and slickensides were found along fracture planes. The Leo zone was faulted out and the lower 521 ft. of hole was drilled in black Cretaceous shale. The No. 5 Novick well, south offset to the Ong well, passed through the fault into black Cretaceous shale at 5532 ft. and was abandoned at 5600 feet.

On the northwest side of the field, Continental Oil Company's No. 3 Emil Rohlff proved to be in close proximity to a fault and at the end of the year was standing waiting for orders and until the completion of No. 4 Rohlff, authorized for the first quarter of 1941.

Maverick Springs Field, Fremont County. The Maverick Springs field, on the Shoshone Indian reservation, Fremont County, entered the Wyoming production column in 1940 for the first time since its discovery in the winter of 1917–1918.

In March 1940, Lloyd Pratt started operating two wells on a lease covering the NE¼ of NE¼ of sec. 27-6N-2W., which had been granted to him by the Secretary of the Interior. These wells were small and are near the line of the probable limit of production. They were drilled by the old McGown Oil Company.

The leases held by The Ohio Oil Co., covering the W½ of sec. 22, NW¼ of sec. 24 and the NW¼ of sec. 26, were assigned and are now under the management of the newly organized Indian Oil Co. of Salt Lake. The production from these leases, amounting to about 115 bbl. of oil per day, is shipped to Ogden, Utah, for refining.

The properties of the Sheridan Wyoming Oil Co. covering the NE¼ of sec. 22-6N-2W., were transferred to the operating management of the Riverton Oil Co. last summer, and under this management the wells are being cleaned out and acidized. Production from three of the wells is now more than 500 bbl. of oil per day. The oil recovered by the Riverton Oil Co. is moved by truck to Riverton, Wyo., and shipped by rail either to Minneapolis or Kansas City, where it brings a price of 50¢ per barrel.

V. M. Kirk, well-known oil operator of Frannie, Wyo., has acquired the holdings of Stanolind Oil and Gas Co. covering the SE¼ of sec. 22 and S½ of sec. 23-6N-2W., and is now cleaning out and acidizing three oil wells on the leases. Up to the first of the year no oil had been moved from the property.

Continental Oil Co. has obtained renewal of its lease covering lands acquired from Union Oil Company of California. The Continental leases have been placed under the management of the Maverick Production Co. (Husky Refining Co., of Cody) and the oil produced will be marketed to the Western Fuel Oil and Supply Co., of Minneapolis.

The Maverick Springs anticline is the type of high Rocky Mountain structure that produces large quantities of oil. The

total closure is well illustrated in U. S. Geological Survey *Bulletin* 711, on the map by A. J. Collier. The possible productive area of Maverick Springs is about 1400 acres. The amount of recoverable oil has been variously estimated as high as 11,000,000 bbl. The present potential of the field is estimated at 7000 to 10,000 bbl. daily. Since all of the new leases issued provide specifically for marketing the oil as a requisite to operation, it is expected that the field will show a high gross production per well during the next few years while the flush is being produced.

Geophysical Operations

Colorado.—Early in the summer of 1940, The Independent Exploration Co. conducted an experimental survey with gravity meter over the Wellington dome, a producing structure in Larimer County, Colorado, with approximately 900 ft. of closure. This work proved that very small gravity anomalies may indicate important structures and that careful interpretation may furnish valuable geological information.

Montana.—The California Company conducted a gravity-meter survey in Montana during the summer of 1940. Most of the work was confined to Daniels and Roosevelt Counties, from the Canadian line southward and eastward to the North Dakota line. This work included a survey of the Wolf Point anticline in Roosevelt and McCone Counties, a large Tertiary structure formed in beds of the Lance formation and covering parts of townships 26, 27 and 28 N., in ranges 47 and 48 E.

This concern also conducted a survey of Poplar anticline, Richland County, one of the more interesting of the eastern Montana structures. The surface axis passes through sec. 36-25N-52E., to the northwest corner of sec. 2-26N-51E., where it may be closed at the Missouri River. The Poplar anticline and the Wolf Point anticline are in alignment with the Baker-Glendive anticline to the southeast and may be continuations of this great regional fold.

While both of these structures may be mapped on surface exposures, it is believed that geophysical methods may be employed to advantage on the other similar folds in this general region, where the surface exposures are not continuous.

The Carter Oil Co. conducted a seismograph survey over the Cedar Creek anticline and will drill a deep test in 1941. The Cedar Creek structure is a closure on the south end of the Baker-Glendive anticline.

Wyoming.—There was a very limited amount of seismograph surveying in Wyoming in 1940. The Sinclair Wyoming Oil Co. devoted some time to a seismograph survey of Lost Soldier, Wertz, Mahoney and East Mahoney domes, in the Lost Soldier Basin, primarily for the purpose of defining participating areas. Continental Oil Co. had a gravity-meter party in this same area and also did some work north of the Big Muddy field along Cole Creek and over Geary and Midway. This party left for the Gulf Coast before the end of the season.

The Mountain Fuel Supply Co. had a seismograph party on the old Ft. Bridger reservation in southwestern Wyoming. This party worked on down into Duchesne County, Utah, before the end of the season.

The Texas Gulf Production Co. completed a seismograph survey of the Rocky Point structure during the summer, and, after establishing about 300 ft. of closure on the critical east side started its test well. This concern also had a gravity-meter party in southeastern Wyoming. Following the completion of this work, a small block of leases was assembled near Wheatland, Platte County.

Oil Pipe Lines in the Rocky Mountain Region

Pipe-line construction in the Rocky Mountain states dropped sharply in 1940

from the more extensive 1939 program, but was equal to, or well above, the average of years prior to 1939.

In Colorado, the Texas Company laid and welded 18 miles of 4-in. pipe connecting its Wilson Creek field in Rio Blanco County with its refinery at Craig by a junction at Iles field in Moffat County with Stanolind Oil and Gas Company's 4-in. line to the Hamilton pump station and then through The Texas Company's line to Craig, a total distance for the old and new lines of 37 miles.

In Wyoming, the Socony-Vacuum Oil Co. connected its Cole Creek field with its White Eagle refinery at East Casper by a 4-in. welded line 13 miles long. Pump station was installed in the field and two 2500-bbl. tanks were erected. Oil began moving through the line in October.

Sinclair Wyoming Oil Co. connected its trunk line from Salt Creek to Parco with the Stanolind line to Freeman, Mo., by laying 27½ miles of 8-in. from its Casper pump station to Clayton tank farm.

Gas Lines in the Rocky Mountain Region

The construction of gas lines in the Rocky Mountain region was limited during 1940. The Montana-Dakota Utilities Co. placed in operation in November a 15-mile line from Glasgow to Nassau, in eastern Montana. This was an extension of the line from the Bowdoin field, Phillips County, to Glasgow, a distance of 32 miles.

The Canadian River and Colorado-Interstate Gas Companies built eight new pumping units on its line from Amarillo, Texas, to Denver, increasing the carrying capacity from 105,000,000 cu. ft. to approximately 125,000,000.

In Wyoming, Northern Pipe Line Co. completed a 90-mile line of 6-in. pipe from Casper to Billy Creek.

Following the resumption of operations in the Powder Wash field, Colorado, Mountain Fuel Supply Co. is preparing to lay 17 miles of 8-in. pipe from the field to a connection with its 16-in. trunk line at Hiawatha.

Acknowledgment

The information contained in this paper has been adapted to the requirements of the A.I.M.E. by abridgment of articles from the annual publication of Petroleum Information, Inc., titled Résumé of Rocky Mountain Oil and Gas Operations for 1940. Special acknowledgment is made to William T. Nightingale, Vice-President of the Mountain Fuel Supply, for assistance in compiling the figures on natural gas production. Beatrice McCune, Secretary of Petroleum Information, Inc., assisted in compiling the tables.

Oil and Gas Developments in Tennessee in 1940

By Kendall E. Born,* Junior Member A.I.M.E.

Production of crude oil in Tennessee during 1940 was slightly more than 15,000 bbl., a decrease from 1939 of about 36,000 bbl. This sharp decline has been caused largely by curtailed activities in the shallow pools in Clay County, where approximately 3000 bbl. was marketed off the lease during the year as against more than 37,000 bbl. in 1939. The flashy production found in 1938 in the Celina area has been short-lived and the area is essentially abandoned. Failure to find steady production has been the major factor retarding developments in the northeastern Highland Rim area. The Mississippi lime production in Scott and Morgan Counties continued to show a steady decline. The Tennessee production by counties is shown in Table 1.

Table 1.—*Oil Production in Tennessee in* 1940

County	Number of Wells Pumped	Production, Bbl.	
		1939	1940
Scott	4	4,332	3,596
Morgan	19	6,479	5,751
Fentress	3	1,2*xx*	1,5*xx*
Pickett	1		1,2*xx*
Clay	8	37,200	3,*xxx*

Developments

There were 32 wells spudded in during 1940, four of which were drilling or only temporarily suspended on Dec. 31, 1940. Twenty-eight wells were completed during the year, four of which were commercial producers. The total footage drilled was 31,214 ft. The more important wildcats are listed in Table 2; the distribution of 1940 oil and gas tests according to physiographic divisions is given in Table 3.

Cumberland Plateau.—There was one completion in the coal area of the state, a test that attempted to extend the Mississippi lime production in the Coon Hollow pool to the southeast in Morgan County. This test encountered only slight shows of oil in the producing horizons of the near-by Coon Hollow and Boone Camp pools.

Some surface work was carried on by private interests during the year in Scott and Morgan Counties and two wells were spudded in early in 1941. The revival of interest in the Kentucky portion of the plateau will probably result in increased activity in this part of Tennessee during 1941. Several sizable blocks of acreage, some by major oil companies, are held in Scott, Morgan, and Cumberland Counties.

Middle Tennessee.—The northeastern Highland Rim continued to be the most active area in the state with 20 completions, although this figure is about one third of the number drilled in 1939. Four oil wells, none with initial productions of more than 100 bbl., were completed in Clay, Fentress, and Pickett Counties. The producing horizons discovered in Pickett and Fentress Counties were in the "Sunnybrook" pays of Trenton age. The Clay County producer was an old test drilled deeper in which oil was found at 671 ft. in the upper part of the Stones River group of limestones, a common pay in this area. All four wells were drilled in or close to old shallow production. Deeper testing into the Knox dolomite group in this area was not particularly encouraging, although one well in Fentress County encountered some saturation at 1860 to 1869 ft. in the upper

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part of the Knox but failed to be commercial after acidizing.

Six wells were drilled on the eastern and western Highland Rim, all of which were dry or near-dry holes. The deepest well, in northwestern Van Buren County, reached a depth of 2765 ft. and penetrated more than 1000 ft. of Knox dolomite. This test logged a good show of oil at 1675 ft. in the upper part of the Knox dolomite group.

Late in the year a considerable amount of surface work, followed by leasing, was carried on in the southern part of the western Highland Rim, especially in Lewis and Wayne Counties.

Western Tennessee.—The Mississippi embayment area of Tennessee continued to attract attention during the year. Surface studies were made in Hardeman, Fayette, and Madison Counties, followed by some leasing. Three wells were drilled in western Tennessee, none of which found encouraging shows of oil or gas. Probably the most interesting, the Pure Oil Company's No. 1 McGregor, in northern Tipton County, found igneous rocks at or near the base of the Upper Cretaceous. This test was located on a pronounced magnetic and seismographic high.

TABLE 2.—*Important Wildcat Tests Drilled in Tennessee during* 1940

County	Location	Total Depth, Ft.	Surface Formation	Deepest Horizon Tested	Drilled by	Initial Production, U. S. Bbl.	Remarks
Clay	4 miles north of Celina	1,330	Trenton	Upper Knox (Ord)	A. F. Engle et al.		Good show of oil with strong sulphur water in upper part of Knox
Dickson	1 mile south of Tennessee City	2,460	L. Mis	Knox (€-Ord)	Glen Rose et al.		Tested Knox on western Highland Rim; structure unknown
Fentress	7½ miles west of Jamestown	840	L. Mis	L. Trenton (Ord)	Travis Smith et al.	50	Discovery well in an area of past shallow production
Lauderdale	1 mile southeast of Gates	2,832	Recent	L. Ordovician	Raymond Gear		Drilled on magnetic high
Pickett	6 miles southeast of Byrdstown	530	L. Mis	L. Trenton (Ord)	Tennessee Oil & Refining Co.	35	Discovery well in an area of past shallow production
Tipton	3 miles northeast of Covington	2,753	Recent	Igneous-Age?	Pure Oil Co.		On a pronounced magnetic and seismographic high
Van Buren	3½ miles west of Spencer	2,765	St. Louis (Mis)	Knox (€-Ord)	Tenn-Ohio Oil Co.		Good show at 1675 ft. in upper Knox; drilled over 1000 ft. of Knox

TABLE 3.—*Physiographic Distribution of Wells Drilled in Tennessee during* 1940

Physiographic Division	County	Number of Wildcats	Number Wells in Proven Fields	Number of Oil Wells	Number of Gas Wells
Cumberland Plateau	Morgan	1	0	0	0
Northeastern Highland Rim	Clay	5	1	1	0
	Jackson	0	1	0	0
	Pickett	5	0	1	0
	Fentress	4	2	2	0
	Macon	1	0	0	0
Eastern Highland Rim	Van Buren	1	0	0	0
Western Highland Rim	Cheatham	1	0	0	0
	Dickson	2	0	0	0
	Wayne	1	0	0	0
Mississippi Embayment	Lauderdale	1	0	0	0
	Obion	1	0	0	0
	Tipton	1	0	0	0

Development and Production in East and East Central Texas for 1940

By D. V. Carter* and Dan C. Williams, Jr.†

Four oil discoveries were made in east and east central Texas during 1940, three of which represented new fields. In the Chapel Hill field, Smith County, oil was found where formerly only gas and distillate were produced. The three oil fields discovered are: Hawkins, Wood County; Pittsburg, Camp County; and Tehuacana, Limestone County. Important extensions were made to the following fields: Bazette, Navarro County; Long Lake, Anderson and Leon Counties; Cayuga, Anderson, Freestone and Henderson Counties; Opelika, Henderson County; and Talco, Titus and Franklin Counties. At the close of the year 54 oil and gas fields were producing in the district. There were 13 other fields, 11 oil and 2 gas, which have been abandoned. The East Texas field led the district in the number of completions for the year. During the year about 622 wells (oil and distillate wells included) were completed and 80 wildcats were drilled.

Production and Proration

During the year 170,424,685 bbl. of oil (distillate production included) were produced in the district—a decrease of 2.6 per cent from the 175,053,729 bbl. (distillate production included) during the preceding year. The district's production for the year 1938 was 182,369,484 bbl. As usual, most of the district's annual production was in the East Texas field, which produced 139,095,694 bbl. (distillate production included) during 1940, or 81.6 per cent of the total oil produced as compared with 141,333,317 bbl. (80.7 per cent) for 1939. The December estimated daily average production in the district was 424,565 bbl. The district accounted for 34.9 per cent of the state's annual production, compared to 36.7 per cent of the state's 1939 production.

The decrease in production for 1940 may be attributed to changes made in proration schedules. Any material changes in the district's annual production may be considered for the most part as a reflection of proration-schedule changes affecting the East Texas field, since it is by far the most important field in the area.

The entire state was subject to 71 shutdown days for the year; the East Texas field to 131; and the Rodessa field (Cass County, Texas, portion) to 5 days. No important changes were made in field rules and regulations during the year regarding the allocation of oil in individual fields in this district.

Discoveries

The Hawkins field is in southeastern Wood County in and principally north of the town of Hawkins. Development to date indicates that the field is somewhat of an elongated anticline trending slightly east of north and the proved oil area appears at this time to cover approximately 4000 acres. The oil production has been secured from the Woodbine sand, Upper Cretaceous; a considerable quantity of gas has been encountered in the Sub-Clarksville formation (Eagleford shale) in the higher part of the structure. It appears that a free gas

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TABLE 1.—*Oil and Gas Production in East and East Central Texas*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
1	Barron,[1] *Limestone*	1939	0	2yy	726	726
2	Bazette, *Navarro*	1939	75	0	106,965	93,963
3	Boggy Creek, *Anderson, Cherokee*	1927	960	0	4,965,186	89,657
4	Bolivar, *Denton*	1937	600	200	10,786	4,515
5	Bosque, South, *McClennan*	1902	2,500	0	105,948	4,660
6	Buffalo,[2] *Leon*	1934	10	7,500	9,640 17,387	2,693 0
7	Carthage,[1] *Panola*	1936	0	250y	5,466	5,466
8	Cayuga,[2] *Anderson, Henderson, Freestone*	1934	4,000	9,000	844,907C 17,561,241	386,919C 3,884,838
9	Cayuga (Trinity),[2] *Anderson, Henderson, Freestone*	1938	y	y	329,675C 10,294	85,320C 5,617
10	Chapel Hill,[2] *Smith*	1938	240	3,000	263,916 52,904	180,299 52,904
11	Collinsville, *Grayson*	1938	100	0	26,932	7,550
12	Corsicana,[5] *Navarro*	1895	6,710	y	14,309,421	153,385
13	Currie,[6] *Navarro*	1921	475	y	6,868,209	37,454
14	East Texas,[2] *Cherokee, Gregg, Rusk, Smith, Upshur*	1930	136,000	2,000	5,946 1,580,885,058	1,113 139,094,581
15	Flag Lake, *Henderson*	1937	300	0	413,318	123,400
16	Ginter, *Angelina*	1936	60	0	24,926	7,675
17	Grapeland,[2] *Houston*	1936	30	x	1,110,834C 83,555	939,291C 31,186
18	Groesbeck,[1] *Limestone*	1913	y	2,360y	0	0
19		1924	y	60y	y	0
20	Hawkins, *Wood*	1940	4,000	x	450	450
21	Hemby (Elkhart),[1] *Anderson*	1938	0	1yy	3,467	2,907
22	Hull,[1] *Panola*	1936	0	19yy	31,481	14,942
23	Huntington, *Angelina*	1936	100	0	11,719	1,394
24	Joaquin,[1] *Shelby*	1931	0	6yyy	78,862C	34,543C
25	Lone Star, *Cherokee*	1938	100	y	23,879	7,377
26	Long Lake,[2] *Anderson, Freestone, Leon*	1933	10,000	y	1,466,609C 3,216,459	1,074,867C 679,140
27	Lott, *Falls*	1937	3yy	0	27,277	5,663
28	Marion County (shallow)	1939	670	x	122,912	115,299
29	Mexia, *Limestone*	1920	3,920	y	97,250,837	570,133
30	Nacogdoches, *Nacogdoches*	1865	1,000y	0	430,923y[9]	4,270[9]
31	Navarro Crossing,[2] *Houston*	1938	1,040	3,451	2,270 406,320	155 190,201
32	Nigger Creek, *Limestone*	1926	170	y	2,999,439	116
33	Oakwood,[2] *Leon*	1939	0	1,000	135 14,331	0 2,995
34	Opelika,[2] *Henderson*	1937	x	x	174,509C 16,199	139,984C 3,703
35	Panola (Bethany),[2] *Panola*	1921	60	23,000y	8,848 50,781	6,485 7,327
36	Percilla, *Houston*	1937	1yy	y	29,551	5,244
37	Pittsburg, *Camp*	1940	x	x	11,230	11,230
38	Post Oak (Chilton), *Falls*	1922	1yy	0	178,187	812
39	Potter (Caddo), *Marion*	1905	980	0	7,651,100	22,778
40	Pottsboro, *Grayson*	1928	20	1,yyy	9,657	1,155
41	Powell,[11] *Navarro*	1923	2,600	y	110,601,183	631,795

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Distillate field.
[2] Oil and distillate field. Upper figure distillate production. Lower figure oil production. C indicates cycling plant.
[5] Includes Mildred, Angus-Edens, Hodge, Burk Rice, Oil Ridge and Old Powell shallow.
[6] Includes North Currie.
[9] Includes production from Chireno and Jennings fields.
[11] Includes shallow production discovered and produced since 1923 in the Powell Woodbine producing area.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil
				During 1940		End of 1940			Number of Wells					
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[a]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average
1	536	536	3	1	0	0	0	3	0	0	2,310	2,125		61.0
2	*x*	*x*	8	4	0	0	8	0	6	2	*y*	*y*		42.0
3	*x*	*x*	33	0	3	0	17	0	0	17	650	*y*		38.5
4	*x*	*x*	10	2	0	3	1	3	0	1	*y*	*y*		40.2
5	*x*	*x*	59*y*	5	11	0	49	0	0	49	*y*	*y*		41.0
6	4,820	1,563	10	1	0	1	1	9	0	0	2,185 2,289	1,832[3] 2,225[4]		48.0 24.7
7	316	258	2	1	0	0	0	2	0	0	*x*	2,630		55.5
8	76,919	19,759	316	20	2	0	272	44	171	101	1,750	1,480	PM	63.0 28.6
9	16,166	4,450	4	0	0	0	1	3	1	0	*y*	*y*	PM	*y* 57.0
10	4,018	2,553	9	8	1	0	3	6	3	0	2,900 *y*	*y* *y*		74.7 62.8
11	*x*	*x*	2	0	0	0	2	0	0	2	390	*y*		43.0 29.3
12	*x*	*x*	2,941*y*	4	0	0	627	0	0	627	*y*	*y*		27.5
13	*x*	*x*	54*y*	0	0	0	13	0	0	13	*y*	*y*		40.5
14	561,217[7]	49,379[7]	26,904	328	372	123	25,921	6	17,831	8,090	1,620	1,054		58.0 39.0
15	*x*	*x*	22	3	3	0	13	0	0	13	1,394	*y*		38.0[8] 45.0
16	*x*	*x*	4	1	0	0	4	0	0	4	*y*	*y*		20.9
17	3,358	3,106	24	15	0	1	1	16	1	0	2,200	2,170	PM	63.8 43.5
18	11,800*y*	*y*	30*y*	0	0	0	0	*x*	0	0	275	*y*		Gas only
19	70	13	5	0	2	0	0	3	0	0	875	*y*		
20	*x*	*x*	1	1	0	0	1	0	1	0	2,026	2,026		15-28.5
21	147	0	2	0	1	1	0	1	0	0	2,200	*y*		59.2
22	1,403	768	2	0	0	0	0	2	0	0	2,660	*y*		64.7
23	*x*	*x*	12	1	3	1	1	0	0	1	*y*	*y*		23.6
24	4,537	286	24	2	0	0	0	14	0	0	2,550	*y*		37.0 48.0
25	*x*	*x*	3	0	0	1	1	0	0	1	1,375	*y*		35.0
26	53,827	14,786	174	36	7	0	115	59	108	7	2,440	2,253	PM	63.0 41.0
27	*x*	*x*	4	1	0	2	3	0	0	3	*y*	*y*		29.3
28	*x*	*x*	38	33	0	1	38	0	0	38	*y*	*y*		40.0
29	*x*	*x*	562*y*	10	37	0	214	0	0	214	*y*	*y*		35.0
30	*x*	*x*	50*y*	2	2	0	40	0	0	40	*y*	*y*		23.0
31	5,024	2,029	29	5	0	1	20	4	20	0	2,700	2,610		*y* 37.5
32	*x*	*x*	75	0	0	1	1	0	0	0	*y*	*y*		40.0
33	30	*y*	6	0	0	0	0	2	0	0	*y*	*y*		*y* 36.0
34	2,835	2,512	6	3	0	0	1	5	0	1	3,250 *y*	3,203 *y*		58.7 38.9
35	150,002	2,029	351	1	*y*	1	4*y*	82	0	4*y*	*y*	*y*		60.0 28.0
36	744	22	2	0	0	1	1	1	0	0	*y*	*y*		41.0
37	*x*	*x*	1	1	0	0	1	0	1	0	3,408	3,408		42.3
38	*x*	*x*	26*y*	1	0	0	1	0	0	1	*y*	*y*		33.0
39	*x*	*a*	66*y*	6	11	0	25	0	0	25	*y*	*y*		40.0
40	*x*	*x*	15	0	0	0	2	0	0	2	300	*y*		38.8
41	*x*	*x*	763	22	34	0	145	0	0	145	800*y*	*y*		37.8

[3] South dome.
[4] North dome.
[7] Includes estimate of gas produced with oil and gas produced from gas wells.
[8] Upper sand.

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
1	Lower Glen Rose	CreL	S	y	5,584	5,611	25	AF	Travis Peak	6,051
2	Woodbine	CreU	S	21-25	2,992	3,008	15	AF	Woodbine	3,008
3	Woodbine	CreU	S	25	3,632	3,666	34	Ds	Fredricksburg	4,648
4	Cisco	Pen	S, L	y	1,630	1,683	25	AF	Ellenberger	2,530
5	Basal Walnut	CreL	DL	y	450	475	3	AF	Trinity	1,800y
6	Woodbine	CreU	S	11	6,150 5,285	6,175 5,695	25 30	D	Washita CreL	6,300
7	Lower Glen Rose	CreL	OL	18-21	4,984	5,040	20	MC	Lower Glen Rose	5,040
8	Woodbine	CreU	S	25	3,680	3,758	78	AF	Trinity	9,085
9	Lower Glen Rose	CreL	L	y	7,600	7,612	10	AF	Trinity	7,612
10	Paluxy L. Glen Rose (Rodessa) L. Glen Rose (Pettit)	CreL	S L L	21 y y	5,600 7,400 8,000	5,700 7,500 8,100	50y 25y 40y	A	Travis Peak	8,600
11	Strawn	Pen	S	y	3,848	4,219	20	ML	Strawn	4,219
12	Nacatoch Corsicana (Wolfe City)	CreU	S	y	800	1,260	12-20	AF	Woodbine	3,570
13	Woodbine	CreU	S	22	2,930	2,990	20	AF	Woodbine	3,646
14	Woodbine	CreU	S	25	3,632	3,665	35	Shore-line	Paluxy	5,020
15	Woodbine	CreU	S	21-25	3,050	3,075	5	AF	Travis Peak	6,518
16	Carrizo	Eoc	S	y	2,186	2,200	10	ML	Wilcox	2,265
17	Woodbine	CreU	S	25	5,976	6,083	25	A	Woodbine	6,257
18	Nacatoch	CreU	S	25.5	710y	750y	40y	AF	Woodbine	3,208
19	Woodbine	CreU	S	20	2,945	2,960	15	AF		
20	Woodbine	CreU	S	y	4,500y	4,919y	150	D	Woodbine	4,963
21	Woodbine	CreU	S	25	5,409	5,422	y		Woodbine	5,487
22	Glen Rose	CreL	L	23	5,930	5,940	10	D	Travis Peak	6,019
23	Queen City	Eoc	S	y	1,458	1,483	8	ML	Mt. Selman	1,490
24	Upper Glen Rose Lower Glen Rose	CreL	L	y	4,097 5,070	4,107 5,138	10 30	D	Glen Rose	5,138
25	Woodbine	CreU	S	y	4,006	4,010	4	Af	Woodbine	4,015
26	Woodbine	CreU	S	25	5,170	5,250	32	A	Trinity	9,966
27	Buda, U Washita	CreL	DL	y	1,250	1,275	10	Af	Edwards	1,500
28	Tokio	CreU	S	y	2,336	2,346	10	A	Tokio	2,346
29	Woodbine	CreU	S	25	3,000	3,085	50	AF	CreL or older	8,847
30	Weches	Eoc	SH	y	80	100	y	ML	CreL	5,484
31	Woodbine	CreU	S	21-24	5,750 5,874	5,900 5,895	Gas 31 Oil 7	Faulted Dome	Woodbine	5,900
32	Woodbine	CreU	S	25	2,820	2,870	15	AF	Woodbine	3,509
33	Woodbine	CreU	S	y	5,838	5,841	3	D	Woodbine	5,913
34	Lower Glen Rose Upper Glen Rose	CreL	LS	18-20	8,170 7,195	8,180 8,028	40	AF	Travis Peak	9,311
35	Various[10]	CreU CreL	S, L	y	1,100	5,700	40	A	Salt	11,303
36	Woodbine	CreU	S	y	5,665	5,670	5	A	Del Rio, CreL	6,634
37	Travis Peak	CreL	S	12-19	7,948	8,035	62	A	Travis Peak	8,087
38	Buda	CreL	L	y	1,025	1,046	10	Af	Trinity	3,567
39	Nacatoch-Tokio	CreU	S	20	1,025 2,300	1,040 2,366	y 15	A	Tokio CreU	2,366
40	Trinity (Basal)	CreL	S	y	830	838	8	MU	Ordovician, or older	6,004
41	Woodbine	CreU	S	25	2,925	3,000	40	AF	Trinity	6,506

[10] Nacatoch 1100 ft., gas; Buckrange 1700, oil; Barlow 2300, gas; Adams 2650, gas; Tiller (Paluxy) 2300, gas; Werner 3600, gas; Jeter (Glen Rose) 5700, gas; Pettit, gas.

cap exists in the Woodbine sand at the crest of the structure. The existence of this "gas cap" decreases the acre-feet of oil-saturated Woodbine sand. Although development has not been sufficient to indicate the regularity of the oil accumulation with respect to subsea depth, it is believed that stratigraphic conditions within the oil reservoir will have a material effect upon the extensions of the field. The Hawkins

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
42	Pulaski Ferry,[1] *Panola*	1936	0	3*yy*	42,244	17,274
43	Red Lake,[1] *Freestone*	1934	0	3,*yyy*	1,605	207
44	Richland, *Navarro*	1924	440	*y*	6,640,904	7,646
45	Rodessa (Dees-Young), *Cass*	1935	5,010	3,250	25,726,536	3,106,350
46	Rodessa (Gloyd), *Marion*	1937	4,035	10,150	9,845,727	2,614,201
47	Rodessa (Gloyd), *Cass*	1936	1,885	10,150	8,010,157	890,863
48	Rodessa,[2] Total		10,930	23,550	43,582,420[12]	6,611,414[12]
49	Rowe and Baker, *Henderson*	1939	80	0	50,013	45,029
50	Shelbyville, *Shelby*	1917	50	0	13,576	2,555
51	Sulphur Bluff, *Hopkins*	1936	855	0	6,458,471	1,518,699
52	Talco, *Franklin, Titus*	1936	7,770	0	39,091,392	8,804,734
53	Tehuacana, *Limestone*	1940	60	0	9,130	9,130
54	Trinity (Kittrel), *Houston*	1934	280	0	1,618,546	119,422
55	Van (Deep), *Van Zandt*	1929	4,520	60	125,865,742	4,434,703
56	Van (Shallow), *Van Zandt*	1933	200	0	290,159	26,533
57	Van, Total		4,720	60	126,155,901	4,461,236
58	Waskom,[2] *Harrison*	1924	1,500	6,000	{ 65,680 77,497	25,322 19,901 }
59	Willow Springs,[1] *Gregg*	1938	0	*x*	16,390	10,587
60	Wortham,[15] *Freestone*	1924	715	0	22,610,359	43,352
61	Total[2]				{ 4,463,210 2,094,802,773*y*	2,929,100[16] 167,495,585 }

ABANDONED FIELDS

Line Number	Field, *County*	Year Discovery	Year Abd.	Oil	Gas	To End of 1940	During 1940
62	Beulah (Lee-Tex), *Angelina*	1935	1935	10	0	750	0
63	Camp Hill, *Anderson*	1935	1937	200	0	289,030	0
64	Cedar Creek, *Limestone*	1927	1930	30	0	330,600	0
65	Chatfield, *Navarro*	1905	1910	0	150	0	0
66	DeBerry, *Panola*	1926	1932	100	50	29,166*y*	0
67	Kosse, *Limestone*	1922	1922	10	0	33,000	0
68	Marlin-Satin, *Falls*	1931	1939	10	0	12,830	0
69	Mexia (Shallow), *Limestone*	1912	1920*y*	0	4,094	0	0
70	Mount Calm, *Hill*	1929	1931	*x*	*x*	27,991	0
71	Redland, *Angelina*	1939	1940	10	0	60	0
72	Rusk, *Cherokee*	1934	1939	200	0	261,134	0
73	Tacoma, *Panola*	1933	1938	40	0	15,750	0
74	Witherspoon-McKie, *Navarro*	1915	1935	400	0	810,495	0
75	Total, Abandoned Fields					1,810,806	
	General total					4,463,210 2,096,613,579*y*	2,929,100[16] 167,495,585

[12] Production by horizons estimated. Includes distillate production.
[15] Wortham shallow discovered in 1912 included with Wortham.
[16] Cycling-plant distillate production included with crude distillate production in fields having cycling plants.

field is the most important oil discovery for this district within the past decade, or since the discovery of the East Texas field.

Bobby Manziel's No. 1 Morrison well is generally considered the discovery well for the Hawkins field, although it was not officially completed until Jan. 11, 1941, or after Jackson and Rotondi's No. 1 Cobb Heirs was completed on Dec. 31, 1940. Subsequent development shows that the

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.			Character of Oil
				During 1940		End of 1940			Number of Wells					
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	Repressuring Operation[d]	Gravity A.P.I. at 60°F., Weighted Average
42	2,786	1,154	2	2	0	0	0	2	0	0	*y*	2,914		61.0
43	1,940	143	3	0	0	1	0	2	0	0	1,855	1,775		*y*
44	*x*	*x*	108	1	0	0	3	0	0	3	*y*	*y*		38.4
45	88,521	14,010	278	0	5	9	259	5	103	156	2,700	904		43.2
46	28,381	10,362	165	0	0	3	151	11	137	14	2,677	1,382		42.0
47	29,725	5,791	72	0	5	3	59	0	23	36	2,700	690		42.0
48	146,627	30,163	515	0	10	15	469	16	263	206				
49	*x*	*x*	4	2	0	0	4	0	1	3	*y*	*y*		31.7
50	*y*	*y*	2	0	0	1	1	0	0	0	*y*	*y*		37.0
51	0	0	73	0	0	0	73	0	7	66	1,900	*y*		22.4
52	*y*	*y*	771	78	35	0	726	0	14	712	1,920	*y*		20.6
53	*x*	*x*	8	5	3	1	3	1	1	2	*y*	*y*		21.0
54	*y*	*y*	20	0	0	0	16	0	1	15	870	*y*		24.0
55	*y*	*y*	575	0	1	0	559[13]	3	332	227	1,230	1,109[14]		34.0
56	*y*	*y*	38	0	1	0	32	0	0	32	*y*	*y*		31.0
57	*y*	*y*	613	0	2	0	591	3	332	259				
58	102,940	4,017	240	10	*y*	3	20	90	0	20	{ *y* 2,040 2,334	*y* 1,950 2,262		*y* 61.8 59.5
59	1,331	863	4	2	0	1	0	3	0	0	2,870	*y*		56.9
60	*x*	*x*	324	4	1	0	11	0	0	11	*y*	*y*		{ 29.0 37.0
61	1,153,393	140,389	35,339	622	540	160	29,464	382	18,762	10,698				
						ABANDONED FIELDS								
62	0		1		0						200*y*	*x*		24.0
63	*y*		10*y*		0						1,950	*x*		40.6
64	*y*		14		0						*x*	*x*		37.0
65	4,750		15		0						250	*x*		Gas
66	*x*		22		0						757	*x*		46.0
67	0		1		0						*x*	*x*		32.0
68	0		2		0						*x*	*x*		34.2
69	20,200*y*		50*y*		0						276	*x*		Gas
70	*x*		2		0						*x*	*x*		31.3
71	0		1		1						*x*	*x*		23.0
72	0		5		0						*x*	*x*		42.0
73	0		3		0						*x*	*x*		46.0
74	0		85		0						*x*	*x*		19.0
75	24,950		211		1									
	1,178,343	140,389	35,550	622	541	160	29,464	382	18,762	10,698				

[13] Three wells producing from Sub-Clarksville.
[14] Brown sand.

Manziel No. 1 Morrison topped saturated Woodbine sand near the oil-water contact; subsea top of saturation is 4477 ft. and subsea bottom of saturation is 4507 ft. This well defines the productive limits of the Woodbine sand in the northwest sector of the field. Maximum net oil-saturated thickness of the Woodbine sand encountered in any well completed to date is approximately 210 feet.

H. S. Moss et al. J. Venters No. 1 in the S. Wright survey was completed Aug. 29,

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
42	Lower Glen Rose (Pettit)	CreL	OL	*y*	5,825	5,905	*y*	MC	Lower Glen Rose (Pettit)	5,905
43	Woodbine	CreU	S	20	4,850	4,950	25	AF	Woodbine	5,002
44	Woodbine	CreU	S	25	2,975	3,040	20	AF	Glen Rose	5,414
45	Dees Young, Lower Glen Rose	CreL	L	17	5,794	6,040	25	AF		
46	Gloyd, Lower Glen Rose	CreL	L	15	6,044	6,094	20	AF		
47	Gloyd Lower Glen Rose	CreL	S, L	16	5,914	6,000	20	AF		
48									Salt, CreL, or older	11,484
49	Woodbine	CreU	S	20*y*	3,140	3,149	6	AF	Woodbine	3,149
50	Blossom	CreU	S, L	*y*	2,690	2,700	10	ML	Georgetown	3,400
51	Paluxy	CreL	S	25	4,487	4,523	36	AF	Glen Rose	6,600
52	Paluxy	CreL	S	20	4,200	4,300	35	AF	Glen Rose	5,903
53	Woodbine	CreU	S	*y*	2,640	2,700	10	AF	Georgetown	2,825
54	Carrizo	Eoc	S	*y*	1,995	2,013	10	Ds	Salt-dome material	3,855
55	Woodbine	CreU	S	*y*	2,682	2,950	268	AF		
56	Nacatoch	CreU	S	*y*	1,200	1,220	20	AF		
57									Travis Peak	7,501
58	Nacatoch, Blossom, Glen Rose, Travis Peak	CreU	LS, S, L	*y*, *y*, 10–15	800	6,160	15–40	A	Travis Peak	6,340
59	Lower Glen Rose (Pettit)	CreL	L	*y*	7,244	7,286	35*y*	D	Cotton Valley	10,284
60	Nacatoch	CreU	S	*y*	1,361	1,371	6	AF	Glen Rose	4,825
	Woodbine	CreU	S	25	2,990	3,050	35	AF		
61										

ABANDONED FIELDS

Line Number	Name	Age	Character	Porosity	Top Prod. Zone	Bottoms Prod. Wells	Net Thickness	Structure	Deepest Zone Name	Depth of Hole, Ft.
62	Queen City	Eoc	S	*x*	2,045	2,053	5		Carrizo	2,324
63	Sub-Clarksville, (Eagle Ford); Woodbine	CreU	S, SH	*y*	5,054	5,059	5	AF	Lower Glen Rose	8,383
64	Woodbine	CreU	S	25	2,885	2,940	10	AF	Woodbine	3,310
65	Corsicana (Wolfe City)	CreU	S	*x*	880	1,020	13	A	Woodbine	3,057
66	Blossom	CreU	S, H	*y*	1,990	2,087	*y*	ML	Blossom	2,125
67	Unknown			*x*	*x*	3,767	*x*	Crev	Glen Rose	6,056
68	Buda	CreL	L	20	1,000	1,160	20	AF	Glen Rose	1,409
69	Nacatoch	CreU	S	25.5	710*y*	750*y*	40*y*	AF	CreL or older	8,845
70	Austin	CreU	C	*x*	607	700	8	F	Travis Peak	3,398
71	Wilcox	Eoc	S	*y*	1,021	1,032	8	ML	Wilcox	1,032
72	Woodbine	CreU	S	20	5,120	5,125	10*y*	MU	Woodbine	5,302
73	Blossom	CreU	S	*y*	2,073	2,085	10	ML	Blossom	2,302
74	Nacatoch	CreU	S	14	825	875	19	AF	Woodbine	3,480
75										

1940, as the opener of the Pittsburg field in Camp County. Oil production was obtained from the Travis Peak at 7948 feet.

The Tehuacana field in Limestone County was discovered by the Zephyr Oil Company's No. 3 Peoples, which was completed as a Woodbine producer from 2808 ft. Several dry holes have been drilled in the area and only three producers have been completed to date.

A gas-distillate-producing horizon was added to the Chapel Hill field in Smith County by the completion in the Paluxy of Shell and Sun's No. 1 B. Moseley in the L. Hands survey. The Pettit oil-producing horizon was discovered by Shell's No. 1 H. Campbell in the Phillip Liveley survey.

As a result of these discoveries many additional blocks of acreage have been leased in Anderson, Cherokee, Raines, Rusk, Smith, Van Zandt, and Wood Counties. It is believed that many important wildcats will be drilled in this area in the next few years.

Several oil wells were completed in the Woodbine sand of the old Wortham field during 1940, with potentials ranging from 25 to 91 bbl. per day.

Price Changes for Crude Oil

With two exceptions, the posted prices of crude oil for the fields in this district were not changed during the year.

Mexia Field.—Sinclair-Prairie Oil Marketing Co., effective July 16, 1940, posted a flat price of \$0.75 per barrel for all gravities, in place of the former schedule of \$0.76 per barrel below 29° A.P.I. gravity with \$0.02 increase per degree up to and above 40° A.P.I. gravity, \$1.00.

Long Lake.—Sinclair Prairie Oil Marketing Co., effective Jan. 20, 1940, posted a

Table 2.—*Summary of Drilling Operations in East and East Central Texas*

Discoveries, Extensions, and Important Wildcats Drilled during 1940

	County	Drilled by	Well No. and Farm	Survey	Producing Formation
1	*Anderson*	R. H. Williamson	1, O. G. Rogers	W. Greenwood	
2	*Bowie*	Shell	1, W. D. Wall	J. Downey	
3	*Camp*	H. S. Moss et al.	1, J. Venters	S. Wright	Travis Peak
4	*Cherokee*	Shell	1, S. H. Maness	J. M. Musquez	
5	*Freestone*	Ark. Fuel Oil Co.	1, P. B. Utley	D. J. Claypool	
6	*Gregg*	R. Lacy	1, Lacy Fee Est.	S. P. Ford	
7	*Harrison*	Fohs Oil Co.	1, R. L. Sypert	R. Hooper	
8	*Harrison*	Fohs Oil Co.	1, M. J. Hall	O. H. P. Bodine	
9	*Hopkins*	Vaughn et al.	1, B. F. Chapman	F. Hopkins	
10	*Houston*	Shell	1, G. E. Dorsey	M. Sallas	
11	*Limestone*	Zephyr Oil Co.	3, Peoples	R. Scott	Woodbine
12	*Limestone*	F. Bryan et al. (Gulf)	1, F. Beville Est.	J. J. Murray	
13	*Panola*	Holcomb & Thomason	1, L. H. Crenshaw	T. Cox	
14	*Panola*	Smith & Turner	1, First State Bk.	G. Gillespie	
15	*Rusk*	J. Z. Werby et al.	1, L. B. McMillan	W. F. Allison	
16	*Rusk*	R. T. Myers et al.	1, D. G. Buckner	D. Warren	
17	*Rusk*	Harrell et al.	1, F & M Bank	M. D. Carmel	
18	*Rusk*	J. S. Harrold et al.	1, M. J. Armstrong	M. D. Carmel	
19	*Sabine*	Sturns & Womack	1, J. H. Keefe	L. Gross	
20	*Shelby*	Superior Oil Co. Tulsa	3, Pickering Lbr. Co.	T. Haley	
21	*Shelby*	Superior Oil Co. Tulsa	4, Pickering Lbr. Co.	W. J. Crane	
22	*Smith*	Shell	1, H. Campbell	P. Liveley	Pettit
23	*Smith*	Sun & Shell	1, B. Moseley	L. Hands	Paluxy
24	*Smith*	Camerson Corp.	1, T. Simpson	R. Walters	
25	*Wood*	B. Manziel et al.	1, F. M. Morrison	J. Pollock	Woodbine

price of $1.08 per barrel flat. This price remained in effect throughout 1940.

Sulphur Bluff.—In this field, in Hopkins County, the American Liberty Pipe Line Co. disposed of its connections to the Talco Pipe Line Co. but no change in price was made.

Construction of Pipe Lines

The Pan-American Pipe Line Co. completed a gathering system in the East Texas field and a trunk line from the field to its Tidewater Terminal at Texas City, Texas. The trunk line consists of 58 miles of 10-in. pipe, 144 miles of 12-in. pipe, and two 8-in. lines for a distance of 12 miles; total length, 214 miles.

The Southern Pipe Line Co. installed gas pipe lines from the Willow Springs field, Gregg County, 2½ miles, to the city of Longview, and 11 miles of line to Gladewater. About 10 miles of additional gas lines has been completed between Gladewater and Kilgore and 6 miles in the Willow Springs-Greggton-Longview area.

Cycling and Pressure-maintenance Projects and Salt-water Disposal

Three cycling and pressure-maintenance plants were completed during the year. Tidewater-Seaboard placed its plant in the Cayuga field in operation on May 1, 1940. The daily capacity of this plant is 40 million cu. ft. and the processed gas is returned to the reservoir at a wellhead pressure of 1245 lb. The Lone Star plant, in the Grapeland field, placed in operation on June 24, 1940, has a capacity of 70 million cu. ft. per day and will operate with an average input pressure of 2800 lb. The Grapeland Oil Co. has had a plant with a capacity of 55

Table 2.—(*Continued*)

Discoveries, Extensions, and Important Wildcats Drilled during 1940

	Depth Completed	Total Depth	Deepest Horizon Tested	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
				Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1		5,407	Woodbine						Dry hole
2		6,222	Travis Peak						Dry hole
3	8,087	8,087	Travis Peak	152		¼	250	300	Discovery well, Pittsburgh field
4		4,788	Georgetown						Dry hole
5		4,506	Georgetown						Dry hole
6		7,308	Pettit		0.08		2,945		Gas distillate
7		4,559	Paluxy						Dry hole
8		4,693	Paluxy						Dry hole
9		5,913	Travis Peak						Dry hole
10		10,900	L. Glen Rose						Dry hole
11	2,808	2,808	Woodbine	10					Discovery well, Tehuacaua field
12		4,942	Travis Peak						Dry hole
13		6,111	Travis Peak		40				Gas well
14		5,040	L. Glen Rose		17.5		2,303		Gas distillate
15		4,140	Georgetown						Dry hole
16		4,335	Georgetown						Dry hole
17		6,802	Travis Peak						Dry hole
18		7,506	Travis Peak						Dry hole
19		6,173	Mid-Way						Dry hole
20		7,193	L. Glen Rose						Dry hole
21		6,085	L. Glen Rose						Gas well in Paluxy
22	8,068	8,600	Travis Peak	878		⅜	1,500	665	Discovery well, Pettit, oil, Chapel Hill field
23	5,810	8,254	Travis Peak	202	7		2,100	2,093	Discovery well, Paluxy, Gas Dist., Chapel Hill field
24		5,508	Woodbine						Dry hole
25	4,919	4,963	Woodbine	124					Discovery well, Hawkins field

million cu. ft. per day in operation in the Grapeland field since August 1940.

Disposal of salt water to suitable reservoirs in several fields in this district continues to be the accepted method of handling what formerly was a troublesome problem in fields where salt-water disposal was deemed necessary.

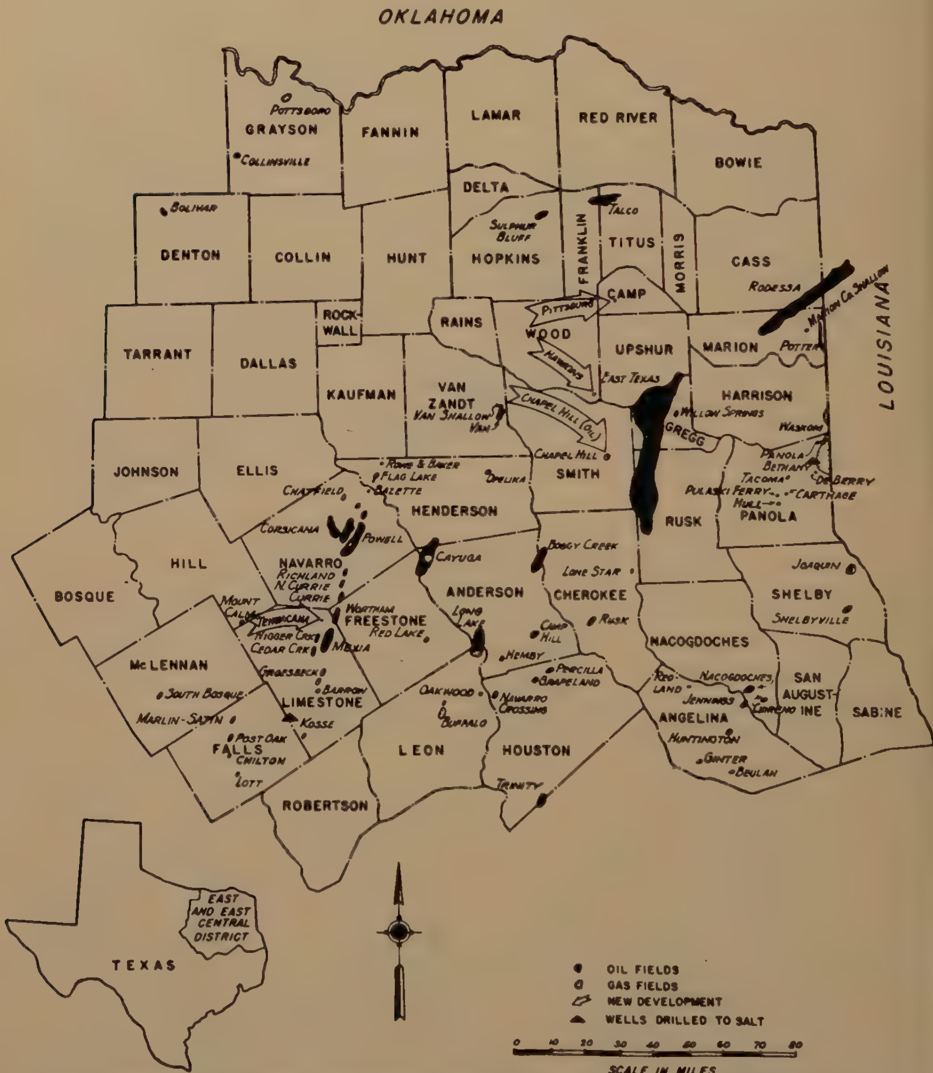

FIG. 1.—LOCATION OF OIL AND GAS FIELES, EAST AND EAST CENTRAL TEXAS (TEXAS RAILROAD COMMISSION DISTRICTS 5 AND 6).

ACKNOWLEDGMENTS

The authors wish to express their appreciation and thanks to the following companies and individuals for their cooperation in furnishing data: Dr. F. V. L. Patten, Texas Railroad Commission, Austin, Tex.; Mr. Donald F. Rowland, American Liberty Oil Co., Dallas, Tex.; Mr. R. O. Garrett,

TABLE 3.—*Production Statistics, East Texas Field*[a]

Date, Year 1940	Average Reservoir Pressure at −3300 Ft., Lb. per Sq. In.	Production, Bbl. (42 U. S. Gal.)	Number of Days Shut Down
Jan. 8.	1,061.35	12,386,445	13
Feb. 8.	1,063.82	11,719,359	12
Mar. 8.	1,065.51	12,393,616	13
Apr. 8.	1,059.95	12,421,746	12
May 8.	1,056.16	11,761,458	14
June 8.	1,059.61	10,359,773	14
July 8.	1,064.14	12,432,722	7
Aug. 8.	1,063.60	11,436,648	9
Sept. 8.	1,060.08	10,883,881	9
Oct. 8.	1,059.68	11,410,725	9
Nov. 8.	1,057.76	10,872,871	9
Dec. 8.	1,054.39	10,860,995	10
	Average 1,060.50	Total 138,940,239	131

[a] Data from Texas Railroad Commission. Late reports increased total production to 139,094,581 barrels.

Arkansas Louisiana Gas Co., Shreveport, La.; Mr. J. S. Hudnall, Tyler, Tex.; Messrs. Morgan J. Davis, Perry Olcott, and J. I. Riddle, Jr., Humble Oil and Refining Co., Houston, Tex.; Messrs. L. T. Potter and E. A. Brown, Lone Star Gas Co., Dallas, Tex.; Mr. Walter Ziegler, H. S. Moss Petroleum Co., Dallas, Tex.; Mr. L. A. Ogden, Pure Oil Co., Ft. Worth, Tex.; Mr. Melbert Schwarz, Seaboard Oil Co., Dallas, Tex.; Mr. F. E. Heath, Sun Oil Co., Dallas, Tex.; Mr. E. L. Rawlins, Union Producing Co., Shreveport, La.; Mr. L. A. Hancock, Magnolia Pipe Line Co., Gregg-ton, Tex. They wish also to thank the following Magnolia Petroleum Company employees for assistance in the preparation of this paper: Messrs. C. A. Awalt, J. A. Walker, W. B. Powers, Lester T. Daniels, J. W. Clark, Wade Smith, M. S. Priddy, Mrs. Margaret Lindsey and Mrs. Jessie Myers, Dallas, Texas.

TABLE 4.—*Oil Recovery Data on Older Woodbine Fields as of January* 1, 1941

Field	County	Cumulative Production, Bbl.	Proved Acres	Net Thickness, Ft.	Acre-Feet	Cumulative Production, Bbl. per Acre-foot
Boggy Creek	Anderson	4,965,186	960	34	32,640	152
Cayuga	Anderson, Cherokee	17,561,241	4,000	78	312,000	56
Currie	Navarro	6,868,209	475	20	9,500	723
East Texas	Cherokee, Gregg, Rusk, Smith, Upshur	1,580,885,058	136,000	35	4,760,000	332
Mexia	Limestone	97,250,837	3,920	50	196,000	496
Nigger Creek	Limestone	2,999,439	170	15	2,550	1,176
Powell	Navarro	110,601,183	2,600	40	104,000	1,063
Richland	Navarro	6,640,904	440	20	8,800	755
Van (Deep)	Van Zandt	125,865,742	4,520	268	1,211,360	104
Wortham	Freestone	22,610,359	715	35	25,025	904
Cedar Creek[a]	Limestone	330,600	30	10	300	1,102
Rusk[a]	Cherokee	261,134	200	10	2,000	131

[a] Abandoned fields.

Oil and Gas Production in the Texas Gulf Coast during 1940

By P. B. Leavenworth*

Twenty-six fields were found in the Texas Gulf Coast in 1940 as compared to 17 fields in 1939. Of these, 14 were oil fields and 12 were gas and distillate. About 150 wells were drilling at the end of the year.

Production for the year 1940 amounted to 104,127,247 bbl. as compared to 100,-253,937 bbl. for 1939.

Considerable wildcatting for Wilcox production featured the exploration, but discoveries were few and the type of fields found mainly gas and distillate. On the whole, the program was discouraging.

New Fields

Alta Loma, Galveston County.—The Alta Loma field was discovered on May 20, 1940, by the Stanolind Oil and Gas Company's No. 1 John A. Hulen, which blew out at a depth of 9166 ft. and ran wild for several days, with an estimated production of 400 bbl. per hour of 36° gravity oil from a sand in the top of the Frio. Water soon appeared but the well produced more than 130,000 bbl. of oil between May 20 and June 10, together with a large amount of salt water. Later the well was killed and recompleted on Nov. 23, for 276 bbl. of 34° gravity oil per day.

Probably this was the most sensational discovery of the year, although development to the end of the year was disappointing. The discovery was the result of reflection seismograph work of the Stanolind Oil and Gas Co., the principal leaseholders.

Bailey's Prairie, Brazoria County.—Glenn H. McCarthy's No. 1 W. B. Munson was completed in a lower Frio sand from perforations 11,345 to 11,349 ft. for 8 bbl. of fluid (50 per cent black oil, 27° gravity, and 50 per cent B. S. and W.) on Sept. 24, 1940. It was finally recompleted as a gas well from perforations 11,631 to 11,651 ft., on Oct. 9, 1940. The well had been drilled to a total depth of 11,860 ft. This well produced for only a short time and the area is at present inactive.

Blessing, Matagorda County.—The Texas Company's No. 1 A. B. Pierce was completed from a Frio sand from 8265 to 8300 ft. on July 8, 1940, for an initial production of 29 bbl. of distillate, 1½ million cu. ft. of gas. One other gas and distillate well was completed in 1940.

Borden, Wharton County.—J. F. Hutchins' No. 2 A. P. Borden Estate was completed on Feb. 11, 1940, for 108 bbl. of 35.6° gravity oil, from a Frio sand at 4758 to 4771 ft. This is the second well drilled in the area by Hutchins. Two other wells in 1940 were failures and there was no activity at the end of the year.

Dyersdale, Harris County.—The Dyersdale field was opened by the completion, on Sept. 15, 1940, of H. C. Cockburn's No. 1 G. Burkitt from a sand in the top of the Frio, through perforations from 4067–4072 ft., for 240 bbl. of low-gravity oil. By the end of the year the field had been fairly well outlined and did not appear to be a major discovery.

Duck Bay, Calhoun County.—Coronado Oil Company's No. 1 Welder, after having drilled to 10,002 ft., perforated casing from 5654½ to 5659 ft. and was completed for 60 bbl. of 36.8° gravity oil on July 27, 1940, from a Miocene sand.

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* Gulf Oil Corporation, Houston, Texas.

TABLE I.—*Oil and Gas Production in Texas Gulf Coast*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
1	Aldine, *Harris*	1939	20	200	31,450	15,158	None	None
2	Allen, *Brazoria*	1927	10	0	90,894	1,187	63	None
3	Alta Loma, *Galveston*	1940	*y*	*y*	379,116	379,116	0	0
4	Amelia, *Jefferson*	1936	1,250	*y*	4,448,275	892,341	0	0
5	Anahuac, *Chambers*	1935	8,216	0	15,412,070	2,667,556	0	0
6	Angleton, *Brazoria*	1939	300	0	253,589	236,386	0	0
7	Aransas (McCampbell), *Aransas, San Patricio*	1936	2,340	*y*	8,934,861	2,988,640	0	0
8	Arriola, *Hardin*	1932	100	*y*	2,054,327	131,153	0	0
9	Armour, *Matagorda*	1938	100	*y*	118,598	25,722	0	0
10	Bailey's Prairie, *Brazoria*	1940	*y*	*y*	203	203	0	0
11	Bammel, *Harris*	1936	40	0	231,101	86,219	0	0
	Barbers Hill, *Chambers:*							
12	2,300 ft.	1916			Included with Deep			
13	5,200 ft.	1928	570	0	71,033,691	3,203,826	0	0
	Batson, *Hardin:*							
14	350–2,600 ft.	1903	500	0	2,070,877	246,554	0	0
15	4,890–5,600 ft.	1934	150	0	37,878,057	217,133	*y*	*y*
16	Bay City (Van Vleck), *Matagorda*	1934	*y*	*y*	3,541,062	816,829	0	0
17	Beeville (Church), *Bee*	1935	20	0	1,000	0	*x*	0
18	Big Creek, *Fort Bend*	1922	250	*y*	9,904,762	133,252	*y*	*y*
19	Big Hill, *Jefferson*	1923	10	0	13,853	Depleted	*x*	0
20	Big Hill, *Matagorda*	1904	15	0	210,906	1,925	*y*	0
21	Blessings, *Matagorda*	1940	*y*	*y*	1,267	1,267	0	0
22	Blue Ridge, *Fort Bend*	1919	400	*y*	11,374,613	285,926	0	0
23	Boling, *Wharton*	1925	250	*y*	7,165,858	448,537	0	0
24	Bonnie View, *Refugio*	1939	*y*	*y*	4,584	0	*y*	*y*
25	Borden, *Wharton*	1940	*y*	*y*	14,512	14,512	*y*	*y*
26	Brenham, *Washington-Austin*	1926	50	*y*	375,358	7,649	0	0
27	Brookshire, *Waller*	1934	*y*	*y*	22,759	1,806	0	0
28	Buckeye (Wilson Creek), *Matagorda*	1932	150	*y*	853,225	70,912	0	0
29	Burnell (South), *Karnes*	1937	*y*	*y*	816	173,346	0	0
30	Buttermilk Slough, *Matagorda*	1939	50	*y*	7,709	4,681	0	0
31	Ceasar, *Bee*	1934	520	*y*	969,327	42,459	0	0
32	Call, *Newton*	1937	100	*y*	11,416	0	0	0
33	Caplen, *Galveston*	1939	100	*y*	150,629	106,319	0	0
34	Cedar Point, *Chambers*	1938	300	*y*	816,747	431,970	0	0
35	Cheek, *Jefferson*	1937	900	*y*	71,642	0	0	0
36	Chriesman, *Burleson*	1938	*y*	*y*	3,549	3,549	0	0
37	Chocolate Bayou, *Brazoria*	1939	100	*y*	42,955	40,550	0	0
38	Citrus Grove, *Matagorda*	1939	*x*	1,800	*x*	*x*	*y*	*y*
39	Clam Lake, *Jefferson*	1937	450	*y*	180,877	91,307	*y*	*y*
40	Clay Creek, *Washington*	1927	325	*y*	4,449,335	130,721	*y*	*y*
41	Clear Lake, *Harris*	1938	1,100	*y*	548,328	368,152	*y*	*y*
42	Cleveland, *Liberty*	1933	400	*y*	1,239,473	61,716	*y*	*y*
43	Clinton, *Harris*	1936	150	*y*	228,457	45,585	*y*	*y*
44	Colletto Creek, *Victoria*	1934	260	520	1,126,574	117,331	*y*	*y*
45	Cologne, *Victoria*	1939	20	180	6,212	5,011	*y*	*y*
46	Conroe, *Montgomery*	1931	18,900	*y*	116,782,296	9,251,461	*y*	*y*
47	Cordele, *Jackson*	1938	420	850	802,671	744,850	*y*	*y*
48	{Cotton Lake / South Cotton Lake} *Chambers*	1937	900	*y*	2,250,934	719,937	*y*	*y*

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent
1	2	0	0	0	2	0	*x*	*x*	*x*	*x*	0	37–66	
2	1	0	0	0	1	0	0	1	200	*x*	0	34.3	
3	2	2	1	0	2	0	2	0	*y*	*y*	0	34–36	
4	120	1	0	0	116	4	116	0	925	*y*	0	29.2	
5	364	44	2	0	346	10	363	2	3,260	*y*	0	34.4	
6	5	4	2	0	5	0	5	0	*x*	*x*	0	50	
7	338	52	1	0	316	2	292	0	2,220	*x*	*y*	47	
8	20	5	0	0	16	0	11*y*	*y*	*x*	*y*	*y*	30–34	
9	5	0	0	*y*	3	0	3	0	2,000	*y*	*y*	34	
10	1	1	0	0	0	1	1	0	*y*	*y*	*y*	27	
11	19	5	1	*y*	4	8	19	0	*x*	*y*	*x*	58	
12		Included with Deep								*y*	0	27	
13	402	13	0	*y*	171	0	*y*	*y*	296	*y*	0	27	
14		Included with Deep								*y*	0	20–38	
15	1,011	7	0	0	28	0	*y*	*y*	296*y*	*y*	0	20–38	
16	50	12	0	0	50	0	49	1	*y*	*y*	0	36.3	0.087
17	1	0	0	0	0	0	*y*	*y*	*y*	*y*	0	0	
18	87	3	1	0	26	0	26	0	400	*y*	*y*	20–42	
19	8	0	2	0	0	0	0	0	*x*	*x*	0	*y*	
20	3	0	0	0	0	0	0	0	*x*	*x*		*x*	
21	1	1	0	0	1	0	1	0	*y*	*y*	0	56	
22	209	4	0	0	51	0	*y*	*y*	Variable		0	26	
23	177	5	1	0	94	*y*	*y*	*y*	*y*	*y*	0	28.3	
24	*y*	*y*	*y*	*y*	*y*	*y*	*y*	*y*	*x*	*x*	0	55	
25	1	1	1	0	1	0	1	0	*y*	*y*	0	35.6	
26	66	24	*y*	*y*	*y*	*y*	*y*	*y*	*x*	*y*	0	17	
27	1	0	0	0	1	0	*y*	*y*	100	*y*	0	24	
28	2	1	0	0	2	0	1	1	1,045	*y*	*y*	38	
29	43	*y*	*y*	*y*	33	6	*y*	*y*	1,425	*y*	*y*	47	
30	1	0	0	0	1	0	1	0	1,140	*y*	*y*	44.8	0.03
31	42	*y*	*y*	*y*	18	8	0	100%	315	*y*	*y*	22	
32	1	*y*	*y*	*y*	0	0	*y*	*y*	1,475	*y*	0	29.6	
33	12	6	0	0	10	2	10*y*	0	3,300	*y*	0	30–40	
34	18	4	1	0	17	0	17*y*	0	2,750	*x*	0	29.6–36.2	
35	4	1	0	0	0	1	*y*	*y*	2,950	*y*	0	35–40	
36	1	*y*	*y*	*y*	*y*	*y*	1*y*	0	*x*	*x*	0	35.5	
37	3	2	0	0	3	0	3	0	*x*	*x*	0	51	
38	3	0	*y*	3	0	*y*	*y*	*y*	1,500	*y*	0	*y*	*x*
39	18	7	2	*y*	14	0	*y*	*y*	2,500	*y*	0	22	
40	69	2	0	0	52	3	*y*	*y*	*x*	*y*	0	24.7	
41	74	37	3	*y*	60	2	60	0	650	*y*	0	26.4	
42	23	1	1	*y*			*y*	*y*	2,400	*x*	0	39	
43	18	1	1	0	8	3	*y*	*y*	4,800	*x*	0	{22, 48}	
44	33	6	0	0	24	6	*y*	*y*	*x*	*x*	0	*y*	
45	4	1	0	0	0	1	*y*	*y*	1,100	*x*	0	*y*	
46	988	4	1	0	946	3	*y*	*y*	2,275			38	
47	48	0	0	0	42	6	48	0	{80, 340}	*x*		22	
48	74	20	2	0	60	3	*y*	*y*	1,050	*x*		{29.6, 36}	

TABLE I.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
1	Eponides Yegua	Eoc	S	34	6,622	6,634	10	D	Cook Mountain	7,695
2	Miocene	Mio	S	Por	4,346	5,584	10	Ds	Miocene	5,960
3	Frio	Olig	S	Por	9,171	9,184	10	D	Frio	11,117
4	Frio	Olig	S	Por	6,745	6,791	10	D	Frio	8,827
5	Marginulina and Frio	Olig	S	27	7,000	7,085	60	DF	Frio	8,749
6	Frio	Olig	S	Por	10,000	10,500	6	D	Frio	10,994
7	Marginulina and Frio	Olig	S	Por	6,544	7,461	20	Ny	Frio	8,889
8	Miocene Frio	Mio, Olig	S	Por	2,992	4,400	50±	Ds	Vicks	6,743
9	Marginulina and Frio	Olig	S	Por	6,620	6,624	4	N	Frio	7,531
10	Frio	Olig	S	Por	11,345–11,349 11,631–11,651		4		Frio	11,860
11	Cockfield	Eoc	S	18	6,185	6,200	10	Dsf	Wilcox	10,573
12	Pliocene, Miocene	Pli, Mio	S	Por	800	2,300	80–100	Ds	Jackson	8,184
13	Miocene, Frio	Mio, Olig	S	30	3,450	6,690	80–100	Ds	Jackson	8,184
14	Cap rock, Lissie, Lagarto	Pre-Ter	S, L	Por, Cav		1,200	y	Ds	Cook Mountain	6,628
15	Miocene, Oligocene, Yegua	Olig, Eoc	S	Por	5,470	5,500	30	Ds	Cook Mountain	6,628
16	Frio	Olig	S	27	y	y	y	D	Vicksburg	11,467
17	Cockfield	Eoc	S	Por	4,825	4,832	7	F	Upper Saline Bayou	6,013
18	Pliocene, Miocene, Mid-Olig, Frio	Mio, Olig	S	Por	800	4,550	21	Ds	Cook Mountain	8,273
19	Pliocene, Miocene	Pli, Mio	S	Por	1,700	5,958	10–50	Ds	Marginulina	8,290
20	Cap rock-Miocene	Pre-Ter, Mio	L, S	Cav, Por	y	862	y	Ds	x	4,435
21	Frio	Olig	S	Por	8,265	8,300	15	y	Frio	8,971
22	Miocene, Mid-Oligocene, Frio	Mio, Olig	S	30	1,956	4,650	55	Ds	Upper Saline Bayou	5,319
23	Cap rock, Mid-Oligocene, Frio	Olig	L, S	Cav, Por	377 2,500 4,817	500 4,089 5,615	15–60	Ds	Jackson	6,281
24	Frio	Olig	S	Por	4,200	5,250	15	T?	Frio	6,510
25	Frio	Olig	S	Por	4,758	4,771	y	y	Vicksburg	6,557
26	Oakville, Cockville	Mio, Eoc	S	Por	190	1,500	10	Ds	Wilcox	5,039
27	Frio	Olig	S	Por	2,955	2,974	16	D	Yegua	6,802
28	Frio	Olig	S	Por	7,750	9,926	60	DF	Frio, Olig	10,578
29	Cockfield (Pettus)	Eoc	S	Por	3,617	3,674	12	DF	Cockfield	3,936
30	Frio	Olig	S	20	7,850	7,860	10	DF	Frio	9,582
31	Cockfield (Pettus)	Eoc	S	Por	3,021	3,039	15	DF	Saline Bayou	4,230
32	Cockfield	Eoc	S	Por	6,908	6,918	10	NF	Yegua	7,700
33	Miocene	Mio	S	25	7,209	7,500	40	Ds	Oligocene Discorbis	8,805
34	Miocene-Frio	Mio, Olig	S	35	4,413	6,000	25	D	Olig	8,507
35	Frio-Vicksburg	Olig, Eoc	S	Por	7,690	8,565	50	DF	Vicksburg	9,007
36	Edwards	CreL	LS	Por	6,167	6,172	5	F	Edwards	6,172
37	Frio	Olig	S	Por	9,800	9,860	10	D	Frio	11,430
38	Oakville	Mio	S	Por	3,750	4,143	85	A	Frio?	11,612
39	Miocene	Mio	S	Por	2,387	6,000	15	Ds	Frio	8,198
40	Miocene-Claiborne, Wilcox	Mio Olig Eoc	SH	Por	1,124	1,500	120	Ds	Wilcox	8,306
41	Frio	Olig	S	25	5,790	5,979	40	Df	Frio	7,744
42	Cockfield, Yegua	Eoc	S	15	5,700	9,100	8	D	Wilcox	10,075
43	Miocene, Frio, Cockfield	Mio Olig Eoc	S	Por	3,200	8,100	20	D	Cockfield	8,783
44	Catahoula, Frio	Mio, Olig	S	Por	2,861	2,880	10	MF	Yegua?	7,860
45	Catahoula, Frio	Mio, Olig	S	Por	2,860	4,850	25+	NF	Vicksburg	5,168
46	U. Cockfield, Conroe	Eoc	S	27	5,000	5,250	30	D	Wilcox	9,040
47	Miocene, Catahoula	Mio	S	Por	2,654	2,753	15	Df	Vicksburg	5,177
48	Marginulina, Frio	Olig	S	34	6,277	6,531	9	Df	Vicksburg	8,580

TABLE I.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
49	Damon Mound, *Brazoria*	1915	270	0	9,634,737	93,679	*x*	*x*
50	Danbury, *Brazoria*	1929	75	*y*	390,601	108,727	*y*	*y*
51	Diamond Half, *Goliad*	1936	240	0	394,649	43,610	*y*	*y*
52	Dickinson, *Galveston*	1934	3,300		11,795,338	2,623,562	*y*	*y*
53	Dinero, *Live Oak*	1935	350	*y*	82,531	3,406	*x*	*y*
54	Dirks, *Bee*	1934	865	0	5,529,817	522,671	*y*	*y*
55	Duck Bay, *Calhoun*	1940	*y*	*y*	6,955	6,955	*y*	*y*
56	Dyersdale, *Harris*	1940	*y*	*y*	42,130	42,130	*y*	*y*
57	East Bernard, *Wharton*	1940	*y*	*y*	571	571	*y*	*y*
58	East Placedo, *Victoria*	1937	300	0	376,302	141,136	*y*	*y*
59	Edna, *Jackson*	1937	420	*y*	4,093	0	*y*	*y*
60	Edwards Ranch, *Victoria*	1940	*y*	*y*	0	0	Shut in	
61	Esperson, *Liberty*	1929	750	0	6,624,761	803,958	*y*	*y*
62	Eureka Heights, *Harris*	1935	850	*y*	2,276,349	904,447	*y*	*y*
63	Fagan, *Refugio*	1940	*y*	*y*	21,812	21,812	*y*	*y*
64	Fairbanks, *Harris*	1938	3,600	*y*	5,888,687	2,401,640	*y*	*y*
65	Fannette, *Jefferson*	1926	160		2,733,753	178,842	*y*	*y*
66	Fannette (deep), *Jefferson*	1940	220	20	Included with Fannette			
67	Fannin, *Goliad*	1939	0	80	*x*	*x*	*y*	*y*
68	Fig Ridge, *Chambers*	1940	*y*	*y*	10,343	10,343	*y*	*y*
69	Fisher's Reef, *Chambers*	1940	*y*	*y*	1,332	1,332		
70	Fort Merrill, *Live Oak*	1935	20	0	32,000	0	*y*	*y*
71	Francitas, *Jackson*	1938	420	*y*	166,710	90,579	*y*	*y*
72	Ganado, *Jackson*	1937	120		109,921	72,691		
73	Garwood, *Colorado*	1933	40	0	6,687	253	*y*	*y*
74	George West, *Live Oak*	1940	0	20	0	0	*y*	*y*
75	Gillock, *Galveston*	1936	*y*	*y*	Included with Dickinson			
76	Goose Creek, *Harris*	1912	900	*y*	77,865,195	579,319	*y*	*y*
77	Joyce Richardson, *Harris*	1940	*y*	*y*	15,215	15,215	*y*	*y*
78	Greens Lake, *Galveston*	1936	80	*y*	53,189	14,795	*y*	*y*
79	Greta, *Refugio*	1933	4,240	*y*	25,647,265	1,389,012	*y*	*y*
80	Hamman, *Matagorda*	1936	*y*	*y*	2,877,123	1,226,863	*y*	*y*
81	Hankamer, *Liberty*	1929	445	*y*	5,998,184	268,595	*y*	*y*
82	Hardin, *Liberty*	1935	2,700	*y*	5,829,794	1,598,207	*y*	*y*
83	Hartzendorf, *Bee*	1935	*y*	*y*	*y*	*y*	*y*	*y*
84	Hastings, *Brazoria*	1934	5,640	*y*	27,574,905	5,445,349	*y*	*y*
85	Hawkinsville, *Matagorda*	1936	*y*	*y*	2,000	0	0	0
86	Heyser, *Calhoun, Victoria*	1936	3,620	3,620	11,611,915	3,413,604	*y*	*y*
87	High Island, *Galveston*	1922	320	*y*	17,008,546	974,591	*y*	*y*
88	Hillje, *Wharton*	1939	200	*y*	77,331	74,592	*y*	*y*
89	Hitchcock, *Galveston*	1936	140	*y*	719,422	201,833	*y*	*y*
90	Hockley, *Harris*	1932	10	*y*	16,000	0	*y*	*y*
91	Holzmark, *Bee*	1935	20	*y*	8,070	7,470	*y*	*y*
92	Hordes Creek, *Goliad*	1935	80	*y*	55,459	8,428	*y*	*y*
93	Hoskins Mound, *Brazoria*	1906	10	0	31,755	0	*x*	*x*
	Hull, *Liberty:*							
94	500–4,400	1918	120	0	81,979,405	802,422	*y*	*y*
95	4,650–5,161	1932	120	0	9,559,620	1,209,184	*y*	*y*

TABLE I.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent
49	129	1	0	0	35	x	y	y	x	y		26	
50	19	5	3	0	13	1	y	y	500	y		25	
51	y	y	y	y	y	y	y	y	x	y		47	
52	255	22	2	0	122	14	y	y	1,250	y		37.5	
53	y	y	y	y	2		1	1	1,600	y		43	
54	101y	y	y	y	93y	x	y	y	1,000			44	
55	2	2	2	0	2	0	2	0	y	y		{37.6 / 36.8}	
56	8	8	2	0	8	0	8	0	y	y		22.3	
57	1	1	0	0	1	0	1	0				55	
58	Included with Placedo								1,080			38.5	
59	x	0	y	0	y	y	y	y	x	x		y	
60	2	2	2	0	0	2	y	y	x	x		y	
61	91	18	2	0	68	4	y	y	100	y	PM	27	0.02
62	41	4	0	0	40	0	40	0	3,456 at 7,600 ft.	2,676	0	{37 / 51}	
63	5	5	2	0	4	1	4	0				{27.6 / 40.6}	
64	303	32	5	0	290	13	290	0	3,000	y		38.8	
65	32	2	0	0	22	1	x	x	540	y		28	
66	12	12	0	0	11	1	11	0			0	36.4	
67	1y	y	y	y	y	y	y	y	x	y		x	
68	1	1	0	0	1	0	1	0	y	y			
69	1	1	5	0	1	0	1	0				32.6	
70	2	0	0	0	0	0	0	0	1,100	0			
71	8	1	0	0	8	0	y	y	2,450	x		48	
72	11	6	1	0	9	1			2,252			26	
73	4y	y	y	y	y	y	y	y	1,225	x		44	
74	1	1	0	1	1	0	0	0					
75	Included with Dickinson								1,250		0	37.5	
76	906	4	0	0	87	y	y	y	y	y	0	25.5	
77	6	6	0	0	6	0	6	0	y	y	0	45–54	
78	6	3	1	0	4	1	4	0	1,300	y	0	24.4	0.14
79	299	0	0	0	214y	14y	y	y	1,350	y	0	23.2–34.9	
80	40	2	0	y	24	y	19	5	800	y	0	37	
81	50	2	0	y	39	2y	11y	26y	424	y	0	23.4	
82	169	23	3	0	163	3y	131y	9y	900	y	0	37–56	
83	1	y	y	y	1	y	1y		0	0	0	45	
84	693	19	3	0	691	2	669y	22y	2,740	y	0	31.5	
85	1	0	0	0	0	0	0	0	200	0	0	y	
86	264	20	2	y	252	4	253y	9y	880	y	0	32.3	
87	137	5	0	y	136	1	24y	39y	y	y	0	32	
88	14	13	3	y	13	1	y	y	y	y	0	25	
89	14y	y	y	y	14y	y	y	y	880	y	0	29–31	
90	4	1	0	0	1	0	y	y	40	y	0	22	
91	6y	y	y	y	4y	x	y	y	1,050	x	0	44.3	
92	3	y	y	y	2	y	y	y	1,550	x	0	47.6	
93	5	0	0	0	0	x	0	0	x	0	0	21.5	
94	796	27	3	y	129	0	y	y	x	x	0	30	
95	-	Included with Shallow							x	y	0	38	

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
49	Miocene, Mid-Oligocene, Vicksburg	Mio, Olig	SH	Por	1,406	3,800	43*x*	Ds	Vicksburg	8,112
50	Pliocene, Miocene	Pli, Mio	S	Por	1,559	2,141	12	D	Vicksburg	7,689
51	Cockfield (Pettus)	Eoc	S	Por	3,682	3,880	14	DF	*y*	*y*
52	Frio	Olig	S	Por	7,800	9,142	20	DF	Frio	9,463
53	Yegua	Eoc	S	Por	5,200	5,220	7	D	Cook Mountain	5,913
54	Cockfield (Pettus)	Eoc	S	Por	3,819	3,990	16	DF	Yegua	4,776
55	Miocene	Mio	S	Por	5,654	5,661	1	?	Frio	10,002
56	Frio	Olig	S	Por	4,050	4,083	10	Df	Yegua	8,515
57	Cook Mountain	Eoc	S	Por	8,070	8,090	20	?	Cook Mountain	8,461
58	Frio	Olig	SH	Por	6,370	6,382	15	Af	Vicksburg	7,502
59	Catahoula, Frio	Mio, Olig	S	Por	2,646 3,890	2,830 5,350	10	D	Cockfield	7,180
60	Frio	Olig	S	Por	5,030	5,041	5	?	Vicksburg	6,265
61	Miocene, Jackson, Heterostegina	Mio Olig Eoc	S	24	2,275	8,314	15	Ds	Weches	8,926
62	Cockfield	Eoc	S	29	7,662 8,080	7,720 8,100	25	A	Yegua	9,038
63	Frio	Olig	S	Por	2,108	5,898	12	?	Frio	6,715
64	Yegua	Eoc	S	25 30	6,505	7,185	20	AF AC	Cook Mountain	7,940
65	Miocene, Mid-Oligocene, Frio	Mio, Olig	S	20	3,250	8,350	20	Ds	Frio	8,345
66	Frio (Hackberry)	Olig	S	Por	8,204	8,345	*y*	Ds	Frio	8,345
67	Catahoula	Mio	S	Por	2,855	2,860	5	A	Frio	3,512
68	Frio	Olig	S	Por	8,849	8,853	4	D	Frio	8,865
69	Frio	Olig	S	Por	8,962	8,964	2	D	Frio	9,954
70	Yegua	Eoc	S	Por	4,643	4,706	5	D	Lower Saline Bayou	5,424
71	Frio	Olig	S	Por	7,380	7,950	15	A	Frio	9,030
72	Marginulina	Olig	S	Por	5,102	5,111	5	D	Frio	6,544
73	Frio, Lower-Oligocene, Cockfield	Olig, Eoc	S	12.8	4,021	6,203	12	D	Wilcox	10,536
74	Wilcox	Eoc	S	Por	8,340	8,346	6	?	Wilcox	8,386
75	Frio	Olig	S	Por	8,400	8,900	12	DF	Frio	9,463
76	Pli, Mio, Mio-Olig, Frio, Vicksburg	Pli, Mio, Olig	S	Por	1,000	5,894	40	D	McElroy	6,975
77	Yegua	Eoc	S	Por	6,448	6,926	7	D	Cook Mountain	7,759
78	Miocene	Mio	S	20 25	2,712	6,818	10	Ds	Mid-Oligocene	9,636
79	Catahoula, Heterostegina, Frio	Mio, Olig	S	20 33	2,000	3,500	20	A	Vicksburg	7,473
80	Frio	Olig	S	Por	8,182	9,370	10	Ds	Frio	11,465
81	Miocene-Frio	Mio, Olig	S	20*y*	2,650	7,700	29	Ds	Dibol, Jackson	7,681
82	Yegua	Eoc	S	27 31	7,547	7,673	10	D	Yegua	8,110
83	Pettus (Cockfield)	Eoc	S	Por	3,642	3,651	9	A	Yegua	3,907
84	Marginulina-Frio	Olig	S	30	5,157	6,140	200	DF	Vicksburg	8,792
85	Miocene	Mio	S	Por	5,150	6,300	10	Ds	Olig	6,905
86	Frio, Miocene	Mio, Olig	S	25	3,400	6,000	25	D	Frio	6,487
87	Pliocene, Miocene, Frio	Mio, Olig	S	Por	200	6,700	40	Ds	Olig	7,179
88	Marginulina	Olig	S	Por	5,220	5,230	10	D	Frio	7,004
89	Miocene	Mio	S	Por	5,134	5,160	12	D	Frio	10,460
90	Cap rock, Frio	Olig	L S	Cav Por	1,800	2,400	30	Ds	Cockfield	7,510
91	Text. Hockleyensis	Eoc	S	Por	4,065	4,260	*y*	NF	Cockfield	4,458
92	Yegua	Eoc	S	Por		4,575	10	MF	Cook Mountain	6,004
93	*x*	*x*	SH	Por	600	623	23	Ds	Mio	4,126
94	Pliocene, Miocene, Mid-Olig	Pli, Mio, Olig	S	Por	500	4,400	63	Ds	Cook Mountain	9,669
95	Yegua	Eoc	S	Por	4,650	5,804	*y*	Ds	Cook Mountain	9,669

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940
	Humble, *Harris:*							
96	700 ft.	1905	2,100	0	Included with Deep		*y*	*y*
97	5,670 ft.	1928	260	*y*	125,854,777	966,099	*y*	*y*
98	Joe's Lake, *Tyler*	1937	850	*y*	1,645,245	878,206	*y*	*y*
99	Katy, *Waller*	1935	200	10,000	159,352	75,972	*y*	*y*
100	Keeran, *Victoria*	1932	640	640	1,358,800	255,499	*y*	*y*
101	La Belle, *Jefferson*	1937	200	*y*	394,033	19,652	*y*	*y*
102	Lamar, *Aransas*	1937	20	0	1,305	305	*y*	*y*
103	La Rosa, *Refugio*	1938	1,720	*y*	2,273,026	1,245,996	*y*	*y*
104	League City, *Galveston*	1938	550	*y*	1,116,457	729,556	*y*	*y*
105	Lissie, *Wharton*	1940	*y*	*y*	434	434	*y*	*y*
106	Livingston, *Polk*	1933	1,820	*y*	6,148,819	626,690	*y*	*y*
107	Lockridge, *Brazoria*	1936	1,600	1,600	2,502,767	800,856	*y*	*y*
108	Lolita, *Jackson*	1940	*y*	*y*	219,935	219,935	0	0
109	Lost Lake, *Chambers*	1929	65	*y*	998,626	29,819	*y*	*y*
110	Louise, *Wharton*	1933	1,700	*y*	3,004,090	338,662	*y*	*y*
111	Lovells Lake, *Jefferson*	1938	*y*	*y*	1,130,812	832,699	*y*	*y*
112	Lucas, Mount, *Live Oak*	1923	120	*y*	256,448*y*	14,370	*y*	*y*
113	Magnet, *Wharton*	1936	800	*y*	1,289,722	458,721	*y*	*y*
	Manvel, *Brazoria:*							
114	4,016 ft.	1931	692	0	19,546,419	2,749,323	*y*	*y*
115	5,160 ft.	1931	1,750	*y*				
116	Markham, *Matagorda*	1908	210		8,079,829	328,521		
117	Mathis, *Live Oak, San Patricio*	1924	120	*y*	*y*	*y*		
118	Martha, *Liberty*	1939	100		101,517	74,218	*y*	*y*
119	Mauritz, *Jackson*	1935	100		398,915	189,926		
120	McFaddin, *Victoria*	1932	620		1,966,970	776,588		
121	McMurray, *Bee*	1937			Included with Pettus			
122	McNeil, *Live Oak*	1934	70		261,226	19,339		
123	Melon Creek, *Refugio*	1939	210		259,392	131,863		
124	Mineral, *Bee*	1937			12,823	0		
125	Moss Bluff, *Liberty*	1930	10	0	179,235	0	*x*	*x*
126	Mountain View, *Live Oak*	1939	*x*	20	*x*	*x*	*y*	*y*
127	Mount Houston, *Harris*	1940			0	0	*y*	*y*
	Mykawa, *Harris:*							
128	Shallow	1929	350		4,180,634	321,123	*y*	*y*
129	Deep	1930	350		Included with shallow production			
130	Mission River, *Refugio*	1938			*y*	245,428		
131	Nash, *Fort Bend*	1926	120	0	1,665,226	0	*x*	*x*
132	Nome, *Jefferson*	1936	900	0	1,814,044	290,430	*y*	*y*
133	Normanna, *Bee*	1930	70	10	87,889	7,875	*y*	*y*
	North Dayton, *Liberty:*							
134	1,200 ft.	1905	850	0	2,370,406	13,949	*x*	*x*
135	4,800 ft.	1927						
136	North Keeran, *Victoria*	1940	20		5,763	5,763		
137	North Markham, *Matagorda*	1938	80	0	78,016	33,323		
138	North Normanna, *Bee*	1938	10	0	766	766*y*	*x*	*x*
139	Oakville, *Live Oak*	1936	150	290	332,163	213,446		
140	O'Connor, *Refugio*	1931	140	250	538,704	23,936		
141	Old Ocean, *Brazoria*	1934	3,900		10,000,753	4,164,418	*y*	*y*

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.			Character of Oil	
	Completed to End of 1940	During 1940		End of 1940			Number of Wells		Initial	Avg. at End of 1940	Repressuring Operation[d]	Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
		Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift					
96	1,793	25	1	*y*	259	*y*	*y*	*y*	*y*	*y*	0	26.5	
97		Included with Shallow					*y*	*y*	*y*	*y*	0	*y*	
98	42	15	2	0	42	0	42	0	1,425	1,406	0	45.8	
99	11*y*	0	0	0	11*y*	*y*	11*y*	*y*	*y*	*y*	0	52	
100	34	6	0	0	24	2	26	1	1,450	*y*	0	36	
101	6	3	1	0	6	0	6	0	7,000	*y*	0	37.2	0.06
102	1*y*	0	0	0	0	1*y*	*y*	*y*	*y*	*y*	0	0	
103	98	26	5	0*y*	72	4	*y*	*y*	{850 1,775}	*y*	0	39	
104	29	7	1	0	29	0	29	0	1,100–2,100	*x*	0	40.5	
105	1	1	0	0	1	0	1	0	*y*	*y*	0	58	
106	98	1	0	0	87	*x*	32*y*	55*y*	700	*y*	0	40	
107	44	2	0	*y*	43	0	44	0	2,100	*x*	0	26	
108	59	59	0	0	59	0	59	0	*y*	*y*	0	31.1–37.1	
109	13	0	0	0	8*y*	1*y*	0	8	*x*	*x*	0	22.4	
110	50	3	1	0	34	4	26*y*	8*y*	1,850	1,300	0	26–38	
111	72	35	4	0	69	*y*	*y*	*y*	1,850	1,300	0	26	
112	41*y*	*y*	*y*	*y*	*y*	*y*			{874 1,400}		0	36	
113	68	21	0	0	62	1	62*y*	0	*y*		0	25.4	*y*
114	192*y*	10	3	*y*	180	4	*y*	*y*	*x*		0	24	*y*
115									*x*	*y*		26	
116	155	6	4	0	36	*x*	11	25	*x*			{25 40}	
117	4	0	0	4	0	0	0	0	935	*x*		*x*	
118	7	3	2	0	7	0	7	0	3,509	*x*	0	41	*x*
119	4	0	6	0	4	0	4	0	2,467		0	31	0.11
120	76	16	2	0	64	5	63	0	{1,185 1,725}	*x*		21.2	
121									570			47	
122	7*y*	*y*	*y*	*y*	5	*x*	4*y*	1*y*	1,150	*x*		44.3	
123	10*y*	0	0	*y*	10*y*	0	10*y*		*x*			35.5	
124	12								100	*x*		45	
125	5	0	0	0	0	0	0	0	280	0	0	0	0
126	1	*y*	*y*	*y*	*y*	1						*x*	*y*
127	1	1	0	0	0	1							
128	45	0	0	0	27	*x*	0		290	*x*			
129												27.5	
130	7	*y*	*y*	*y*	7	*y*	7	0	{590 1,100}	*y*	0	42.6	
131	24	0	0	0	0	0	0	0	800	0	0	0	
132	44	0	0	0					2,550			26.9	0.25
133	7	0	0	0					150	*y*		38.8	
134	63	1	0	0	11	*x*	*y*	0	*x*			24	
135									400			36	
136	1	1	0	0	1	0	1	0					
137	4	2	0	0	4	0	4	0	3,450		0	37	*y*
138	1	0	0	0	0	0	0	0	*y*	0		46.5	
139	26	8	1	0	22	4	15	7	1,300	*x*		23	
140	10	0	0	0	4	6	1	3	365			22.6	
141	75	32	0	0	75	0	75	0	4,700	*x*		{52 68}	

TABLE I.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
96	Cap rock, Miocene, Oligocene	Pre-Ter, Mio, Olig	A S	Cav Por	600	5,400	40	Ds	Cook Mountain	8,181
97	Mid-Olig, Jackson, Cockfield, Yegua	Olig Eoc	S	Por	5,670	6,500	200	Ds	Cook Mountain	8,181
98	Carrizo, Wilcox	Eoc	S	Por	7,600	7,736	30	DF	Wilcox	9,014
99	Cockfield, Upper Saline Bayou	Eoc	SH	{27 10.2}	7,400	7,500	100	A	Wilcox	11,080
100	Frio	Olig	S	15	5,597	7,011	10	MF	Vicksburg	10,043
101	Marginulina	Olig	S	30	8,206	8,670	11	Ds	Frio	10,147
102	Frio	Olig	S	Por	7,502	7,997	*y*	*y*	Frio	9,785
103	Frio	Olig	S	30	5,382	6,385	20±	DFV	Frio	7,021
104	Discorbis, Frio	Olig	S	30	8,695	10,960	20	D	Vicksburg	11,402
105	Yegua	Eoc	S	Por	6,728	6,734	6	*y*	Wilcox	10,116
106	Conroe, Jackson	Eoc	S	Por	3,285	4,360	20	DF	Cockfield	5,596
107	Frio	Olig	S	20	6,309	6,387	20	AF	Vicksburg	9,684
108	Frio	Olig	S	32	5,274	6,398	4	D	Frio	7,280
109	Marginulina, Frio	Olig	S	Por	2,679	5,157	33	Ds	Frio	7,471
110	Marginulina, Frio	Olig	S	Por	5,135	7,143	15	D	Vicksburg	8,271
111	Frio	Olig	S	30	7,713	7,792	22	Ds	Frio	8,189
112	Catahoula, Frio, Yegua	Olig, Eoc	S, SH	Por	1,750	5,300	28	D	Cook Mountain	6,789
113	Marginulina	Olig	S	Por	5,490	5,560	20	D	Frio	6,518
114	Miocene	Mio	SH	27.9	3,990	4,016	23	D	Vicksburg	7,957
115	Marginulina	Olig	S	22.5	5,000	5,500	26	D	Vicksburg	7,957
116	Cap rock, Pli, Mio, Mid-Mio, Olig	Pre-Ter Pli, Mio, Olig	{L SH}	{Cav Por}	936	4,350	20	Ds	Lower Oligocene, Vicksburg	6,436
117	Catahoula	Mio	S	Por	2,375	2,385	10	ML	McElroy	5,526
118	Yegua	Eoc	S	30	8,100	8,108	5	AF	Yegua	9,109
119	Frio	Olig	S	Por	5,640	5,650	8	ML	Frio	7,408
120	Catahoula, Heterostegina, Frio	Mio Olig	S	Por	{2,440 4,400}	2,470 5,300	{24 10}	AF	Frio	7,025
121	Yegua	Eoc	S	Por	4,267	4,284	8	NF	Yegua	4,379
122	Hockeyensis, Cockfield	Eoc	S	Por	4,434	4,992	10	D	Cook Mountain	6,212
123	Frio	Olig	S	Por	5,856	5,876	20	A	Frio	5,876
124	Cockfield (Pettus)	Eoc	S	Por	3,545	3,650	8	NF	Cockfield	4,536
125	Cap rock, Marginulina	Pre-Ter, Olig	SH	{Cav Por}	800	5,800	33	Ds	Vicksburg	7,375
126	Text, Hockleyensis	Eoc	S	Por	2,476	2,481	10	F	Cockfield	3,000
127	Miocene	Mio	S	Por	3,482	3,486	4		Frio	4,205
128	Miocene, Heterostegina	Mio, Olig	SH	Por	4,100	4,300	30	D	U. Saline Bayou	7,355
129	Frio	Olig	SH	Por	4,400	4,892	30	D	U. Saline Bayou	7,355
130	Frio	Olig	S	Por	5,445	7,150	15±	D	Vicksburg	9,225
131	Miocene, Mid-Oligocene	Mio, Olig	S	Por	3,700	5,677	60*y*	Ds	Vicksburg	6,800
132	Marginulina, Frio	Olig	S	Por	6,010	6,055	12	Ds	Vicksburg	9,045
133	Hockleyensis	Eoc	SH	Por	3,500	3,676	17	D	Yegua	5,038
134	Pliocene, Miocene	Pli, Mio	Ss	Por	400	1,200	*x*	Ds	L. Saline Bayou	6,077
135	Miocene, Frio, Vicksburg	Mio,Olig	SH	Por	4,075	5,188	32	Ds	L. Saline Bayou	6,077
136	Frio	Olig	S	Por	5,550	5,552	2	?	Vicksburg	7,509
137	Frio	Olig	S	Por	7,702	7,730	10	AF	Frio	8,869
138	Pettus (Cockfield)	Eoc	SH	Por	4,218	4,238	5	MF	Cockfield	4,273
139	Mio, Olig, Jackson, Pettus (Cockfield)	Eoc	S	Por	256	2,816	8	AF	Cook Mountain	4,500
140	Miocene	Mio, Eoc	S	Por	2,136	4,150	8	AF	Frio	6,860
141	Frio, L. Oligocene	Olig	S	27	8,632	{8,654 9,965 11,006}	200	D	Frio, Lower	11,357

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
142	Orchard, *Fort Bend*	1926	200	50	3,718,110	67,045	*y*	*y*
143	Orange, *Orange*	1913	850	0	32,776,071	177,700	*x*	*x*
144	Palacios, *Matagorda*	1937	80	*y*	124,806	9,140		
145	Pettus, *Bee*	1930	1,180	1,220	8,868,835	141,631		
146	Pettus, New, *Bee, Goliad, Karnes*	1930	950	50	*y*	230,041	Included with Pettus	
147	Pickets Ridge-Kubela, *Wharton*	1935	1,200		3,223,798	618,785	*y*	*y*
148	Pierce Junction, *Harris*	1921	340	0	34,439,072	623,403	*y*	*y*
149	Placedo, *Victoria*	1935	1,920	*y*	11,198,311	1,710,093	*y*	*y*
150	Pledger, *Brazoria*	1932	3,650	*y*	17,000	*y*	*y*	*y*
151	Plummer, *Bee*	1936	160	220	238,108	38,183	*y*	*y*
152	Port Lavaca, *Calhoun*	1934	220	220	420,806	*y*	*y*	*y*
	Port Neches, *Orange:*							
153	3,150 ft	1928	300	*y*	5,558,866*y*	332,202*y*	*y*	*y*
154	West, 5,944 ft	1936	Included with Port Neches					
155	Powderhorn Lake, *Calhoun*	1939	20	20	*y*	*y*	*y*	*y*
	Raccoon Bend, *Austin:*							
156	3,490 ft	1927	1,624	*y*	17,472,290	456,214	*y*	*y*
157	4,120 ft	1934	1,470	600	5,024,099	760,133	*y*	*y*
158	Ray, *Bee*	1934	420	*y*	1,504,683	60,067	*y*	*y*
159	Refugio, *Refugio*	1922	Included with New Refugio					
160	Refugio, New, *Refugio*	1934	3,820	6,450	41,759,045	1,618,801	*y*	*y*
161	Refugio Fox, *Refugio*	1932	150		Included with New Refugio			
162	Rockland, *Jasper*	1929	80	0	38,717	4,717	*x*	*x*
163	Rosslyn, *Harris*	1938	Included with Fairbanks					
164	Rosenberg, *Fort Bend*	1939	50	*y*	6,048	*y*	*y*	*y*
165	Rowan, *Brazoria*	1940	*y*	*y*	45,232	45,232	*y*	*y*
166	Sandy Point, *Brazoria*	1937	200	0	244,421	30,015	*y*	*y*
167	Saratoga, *Hardin*	1901	538	0	29,425,498	309,283	*y*	*y*
168	Sarco, *Goliad*	1938	40	0	1,728	528	*x*	*x*
169	Satsuma, *Harris*	1936	500	*y*	493,547	112,267	*x*	*x*
	Schwab (Ace), *Polk:*							
170	Shallow	1934	200	0	146,954	8,999	0	0
171	Wilcox	1939	200	*y*	194,173	126,847	*y*	*y*
172	Seabreeze, *Chambers*	1936	(Included with Willow Slough) 1,000	1,000	300,392	73,345	*y*	*y*
	Segno, *Polk:*							
173	Shallow	1936	450	350	2,025,908	378,708	*y*	*y*
174	Deep	1938	1,000	*y*	1,779,949	1,275,929	*y*	*y*
175	Shephard, *San Jacinto*	1940	*y*	*y*	2,330	2,330	*y*	*y*
176	Sheridan, *Colorado*	1940	*y*	*y*	30,893	30,893	*y*	*y*
177	Silsbee, *Hardin*	1936	1,020	*y*	1,911,517	349,198	*y*	*y*
178	Slick, *Goliad-Dewitt*	1930	80	240	74,945	1,831	*y*	*y*
179	Smith Point, *Chambers*	1940	*y*	*y*	6,970	6,970	*y*	*y*
180	Sour Lake, *Hardin*	1902	946	0	79,802,565	416,435	*y*	*y*
181	South China, *Jefferson*	1939	200	*y*	124,288	107,462	*y*	*y*
182	South Houston, *Harris*	1935	620	*y*	5,978,798	627,199	*y*	*y*
183	South Liberty, *Liberty*	1925	250	0	15,791,235	182,546	*y*	*y*
184	Spanish Camp, *Wharton*	1936	0	1,280	0	0	*y*	*y*
185	Spindletop, *Jefferson*	1901	580	0	126,128,691	611,086	*x*	*x*
186	Spindletop (Deep), *Jefferson*	1925	580	0	Included with Spindletop			
187	Splendora, *Montgomery*	1934	100	0	996	0	*x*	*x*

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil	
	Completed to End of 1940	During 1940		End of 1940			Number of Wells						
		Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
142	35	1	0	3	18	0	4	14	375	x		38	
143	324	8	2	0y	46	0	0y	38y	x		0	{20 / 42}	
144	4	0	0	0	4	0	x		x	x		53	
145	88	0	0y	x	28	0x	0y	28	236			45	
146												47.5	
147	76	12	3	0	63	3	58	5	2,053	y	0	25	
148	264	12	1	0	91	x	y	y	355			27.6	
149	179	7	0	0	171	5	101	70	1,900	y	0	25	
150	12	0	0	0	0	1	0	0	2,450	y	0	55.8	
151	y	y	y	y	y	y	y	y	1,010	y	0	25	
152	13	0	0	0	2	3	y	y	x	x	0	61	
153	34	9	1	0	30	0	y	y	x	x	0	25	
154											0	38	
155	1	0	0	1	0	0	0	0	1,850	y	0	54	
156	160	0	0	0	80	1	1y	79y	275	y	0	28.2	
157	90	1	2	0	85	1	68y	17y	1,800	x	0	34.1	
158	11	0	0	0	11	0	0	11	1,755	y	0	46	
159									550–2,000	y	0	33	
160	506	5	1	y	158	y	120	38	1,500±	y	0	39	
161									700–200	y	0	38–42	
162	10	2	1	0	2	0	y	y	x	y	0	21–25	
163	1	y	y	y	1	y	1	y	1,800	y	0	39.2	
164	2	1	3	0	2	0	2	0	y	y	0	55	
165	7	7	1	0	7	0	7	0	y	y	0	41–55	
166	10	2	1	0	6	1	y	y	2,680	1,520	0	40	
167	768	2	0	y	247	0	y	y	y	y	0	20	
168	1	0	0	0	1	0	y	y	x	x	0	35	
169	16	0	0	0	15	1	15	0	3,100	x	0	40.6	
170	4	1	1	0	4	0	4	0	x	x	0	39	
171		Included with Shallow										40–64	0.10
172	11	3	0	0	8	3	8	0	3,900	x	R	40–50	0.07
173		Included with Deep							1,450	x	0	39.5	
174	111	37	1	0	107	0	103	4	950	x	0	36.8	
175	1	1	1	0	1	0	1	0	y	y	0	55.7	
176	3	3	0	0	3	0	3	0	y	y	0	35	
177	51	3	0	0	47	2	44	3	574	550±	0	44	
178	5	0	1	0	1	x	0	1	550	y	0	46	
179	3	3	4	0	3	0	3	0	y	y	0	36–50	
180	795	13	0	0	179	0	17y	162y	y	y	0	16–31	
181	17	14	5	0	17	0	17	0	y	y	0	37–52	
182	78	4	0	0	78	0	69	29	2,085	2,019	0	19.5–25.5	
183	309	8	0	0	48	0	12y	36y	50	y	0	21–47	
184	10	2	0	0	0	10	0	10	1,300	y	0	y	
185	1,384	6	0	0	159	0	y	y	x	x	0	25	
186												26	
187	5	0	0	0	0	0	0	0	2,000	0		69	

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
142	Miocene, Frio, Cockfield, Saline Bayou	Mio Olig Eoc	S	20	1,266	7,900	25	Ds	Crockett	10,085
143	Pliocene, Miocene, Mid-Oligocene, Frio	Pli Mio Olig	S	Por	2,500	6,123	30x	Ds	Frio	7,602
144	Frio	Olig	S	Por	7,830	9,275	{10 15}	D	Frio	11,327
145	Cockfield (Pettus)	Eoc	S	Por	3,860	3,900	19	DF	Wilcox	8,993
146	Cockfield (Pettus)	Eoc	S	32	3,616	3,926	15	DF	Mt. Selman	7,569
147	Marginulina	Olig	S	33	4,690	4,710	10–25	A	Hockleyensis	8,888
148	Miocene, Frio, Vicksburg	Mio, Olig	S	Por	3,142	6,710	45x	Ds	Hockleyensis	7,165
149	Heterostegina, Frio	Olig	S	Por	4,745	6,370	20	AF	Frio	7,242
150	Marginulina, Frio	Olig	S	Por	6,650	6,800	100	D	Vicksburg	8,115
151	Pettus, Cockfield	Eoc	S	Por	3,036	4,277	y	NF	Cook Mountain	4,256
152	Marginulina	Olig	S	Por	6,240	6,250	10	DF	Frio	7,498
153	Pliocene, Miocene	Pli, Mio	S	Por	3,150	5,929	22	Ds	Vicksburg	7,667
154	Frio	Olig	S	Por	5,920	5,942	40	Ds	Vicksburg	7,667
155	Miocene	Mio	S	Por	4,628	4,635	7	AF	Mio, Olig	6,652
156	Oakville Whitsett, McElroy	Mio, Eoc	S	25	3,150	3,490	18	Df	Wilcox	8,599
157	Cockfield	Eoc	S	25	4,070	4,150	35	Df	Wilcox	8,599
158	Pettus, Cockfield	Eoc	S	Por	3,888	3,944	15	DF	Yegua	4,253
159	Oakville, Catahoula, Frio	Mio, Olig	S	Por	3,687	6,770	30	DF	Vicksburg	9,225
160	Frio	Olig	S	30	4,900	6,600	30	DF	Vicksburg	9,225
161	Marginulina	Olig	S	34	3,545	5,900	10	D	Frio	7,300
162	Cockfield	Eoc	S	Por	1,260	1,275	6	MF	Cook Mountain	Below 3,000
163	Yegua	Eoc	S	Por	6,947	6,956	9	AF	Yegua	7,495
164	Cockfield	Eoc	S	Por	7,719	7,743	10	Ds	Cook Mountain	8,698
165	Frio	Olig	S	Por	8,516	8,968	18	y	Frio	10,010
166	Marginulina, Frio	Olig	S	30	6,480	6,500	3	T	Vicksburg	8,943
167	Cap rock, Lagarto, Mio, Olig	Pli, Mio, Olig	SL	{Por Cav}	500	3,320	17	Ds	Crockett	7,461
168	Frio, Vicksburg	Olig	S	Por	5,013	5,023	x	F	Yegua	6,702
169	Yegua	Eoc	S	20	6,800	6,832	15	A	Yegua	7,520
170	Yegua	Eoc	S	Por	1,806	4,843	10	D	Wilcox	9,667
171	Wilcox	Eoc	S	20.1	7,786	7,799	10	D	Wilcox	9,667
172	Frio	Olig	S	22	8,110	8,600	25	D	Frio	9,636
173	Cockfield	Eoc	S	Por	5,000	5,200	10	AF	Wilcox	9,154
174	Wilcox	Eoc	S	17.5	8,100	8,150	30	AF	Wilcox	9,154
175	Wilcox	Eoc	S	Por	8,215	8,277	y	y	Wilcox	8,590
176	Wilcox	Eoc	S	Por	8,133	8,144	7	y	Wilcox	8,339
177	Cockfield	Eoc	S	Por	6,845	6,965	20±	DF	Cook Mountain	7,778
178	Yegua-Cockfield	Eoc	S	Por	4,199	4,404	10	DF	Yegua	4,580
179	Frio	Olig	S	Por	8,796	10,343	15	DF	Frio	10,491
180	Pli, Mio, Olig, Jackson, Upper Saline Bayou	Pli, Mio, Olig	S	Por	500	6,804	100	Ds	Upper Saline Bayou	7,914
181	Frio	Olig	S	Por	7,491	7,885	30	Ds	Frio	8,785
182	Miocene-Frio	Mio, Olig	S	30	3,845	4,775	75±	Ds	Yegua-Cockfield	9,470
183	Miocene, Olig, Jackson-Yegua	Mio, Olig, Eoc	S	Por	700	4,996	100±	Ds	Upper Saline Bayou	5,174
184	Catahoula	Mio	S	Por	2,910	3,020	30	N?	Yegua	8,183
185	Cap rock, Pliocene	Pre-Ter Pli	{L S}	{Cav Por}	800	1,200	x	Ds	Vicksburg	7,382
186	Miocene, Frio, Mid-Oligocene	Mio, Olig	S	Por	2,920	5,900	69	Ds	Vicksburg	7,382
187	Cockfield	Eoc	S	Por	5,835	5,824	5	D	Cockfield	6,452

East Bernard, Wharton County.—Cockburn Oil Corporation's No. 1 Leveridge was completed on May 11, 1940, for 25 bbl. of distillate and 2½ million cu. ft. of gas, from a sand in the Cook Mountain section. This was the third well drilled in the area. No further development was undertaken during the remainder of the year.

Edwards Ranch Gas Field, Victoria County.—Titanic No. 2 (No. 1 "A"), T. C. Edwards, was completed as a gas well from a Frio sand at 5036 to 5041 ft. on May 10, 1940.

Fagan, Refugio County.—Norsworthy No. 1, B. J. Fox, was completed for 91 bbl. from a Frio sand at 5895 to 5898 ft. on Feb. 12, 1940. Further development in the area was disappointing.

Fig Ridge, Chambers County.—Sun Oil Company's No. 1 Carrie Smith was completed for 84 bbl. of oil on July 9, 1940, from perforations in a Frio sand from 8849 to 8853 ft. No other wells were drilled in this area in 1940. The discovery was the result of reflection seismograph work by the Sun Oil Co., which controls leases in the area.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940
188	Stratton Ridge, *Brazoria*	1932	25	0	12,214	0	*x*	0
189	St. Charles, *Aransas*	1940	20	20	*x*	*x*	*y*	*y*
190	Sugarland, *Fort Bend*	1928	1,165	0	30,002,539	1,354,672	*y*	*y*
191	Telferner, *Victoria*	1937	30	30	42,990	8,102		
192	Terrell, *Victoria*	1940			3,240	3,240		
193	Texana, *Jackson*	1939	100*y*		1,708	*y*		
194	Thomaston, *DeWitt*	1940	40		2,924	2,924		
195	Thompsons, *Fort Bend*	1931	4,550		38,836,830	4,387,327		
196	Thompsons (Vicksburg), *Fort Bend*	1939	600		Included with Thompsons			
197	Toland, *Refugio*	1939		40	2,492*y*	*y*	*y*	*y*
198	Tomball, *Harris*	1933	8,750		16,462,558	2,524,462		
199	Tom O'Connor, *Refugio*	1934	8,920	0	21,243,297	5,822,218		
200	Tuleta, West, *Bee*	1932	160	0	1,864,876	57,230		
201	Tulsita, *Bee*	1938	30	30	6,831	3,208		
202	Turtle Bay, *Chambers*	1935	820		1,494,257	246,132		
203	Vanderbilt, *Jackson*	1934		Included with West Ranch				
204	Victoria, *Victoria*	1939	200	0	113,719	113,719	*y*	*y*
205	Voss, *Bee*	1936	95	0	78,158	1,982		
206	Webster (Friendswood), *Harris*	1937	4,000		6,425,406	2,535,772		
207	Weser, *Goliad*	1936	140	0	1,700	1,700		
208	West Beaumont, *Jefferson*	1936	450		3,046,678	1,140,278		
209	West Columbia, *Brazoria*	1914	500		86,559,776	2,343,615		
210	West Columbia (New), *Brazoria*	1936						
211	West Ganado, *Jackson*	1940			3,638	3,638		
212	West Orange, *Orange*	1937	220	0	1,726,965	726,775		
213	West Ranch, *Jackson*	1938	4,860	*y*	2,307,206	1,855,434		
214	White Creek, *Live Oak*	1939	115	0	130,818	99,180		
215	Willow Slough, *Chambers*	1937		Included with Seabreeze				
216	Withers, *Wharton*	1936	3,800		4,818,880	1,754,026		
217	Withers (Five Corners), *Wharton*				Included with Withers			
218	Wilson Creek, *Matagorda*	1937	40		Included with Buckeye			
219	Worth, *Bee*	1935	50	0	27,275	*x*	*x*	*x*

Fisher's Reef, Chambers County.—Humble Oil and Refining Company's No. 2 "C" State lease on section 46, Galveston Bay, was completed in a Frio sand from 8961 to 8963 ft. for 144 bbl. of oil, on Nov. 11, 1940. Several other wells in the area were failures.

George West, Live Oak County.—E. M. Jones' No. 1 "B" George W. West Estate was completed as a distillate well in the Wilcox from 8340 to 8346 ft. on Oct. 29, 1940. No further development was undertaken during the year.

Joyce Richardson, Harris County.—Joyce Richardson's No. 1 Emil Marks opened production by completion at 6918 to 6926 ft. for 27 bbl. of distillate, on July 10, 1940, from a Yegua sand. Numerous wells had previously been drilled in the area, several of which had shows of oil or gas. Other wells have since been completed but the field does not appear to be of major importance.

Lissie, Wharton County.—Gulfboard Oil Corporation's No. 1 Winnie Poole had been previously drilled to 10,116 ft. and failed to produce in the Wilcox. The well was

TABLE 1.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil	
	Completed to End of 1940	During 1940		End of 1940			Number of Wells		Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent
		Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift					
188	4	0	0	0	0	0	0	0	*x*	0		32.5	
189	1	1	1	0	1	0	1	0				60.8	
190	71	0	0	0		0			1,570	*x*		27–35	
191	3	0	0	0	3	0	2	1	900			27.8	
192	1	1	0	0	1	0	0	1				30.3	
193	1	0	0	0	1	0	1	0	*x*			52	
194	2	2	0	0	2	0	2	0				{30.6 52.3}	
195	362	71	6	0	345	*x*	315*y*	30*y*	2,430	*x*		25	
196												35.7	
197	1								2,520				
198	518	25	3	0	452	61	417*y*	35*y*	2,490	*y*		41	
199	433	24	0	0	428	*x*	427	1	1,040			35.5	
200	75								792	*x*		{50 44.5}	
201	3	0	0	0	1	0	1	0	1,450*y*	*x*		45	
202	37	2	1	0	35	2	33	2	2,948	2,861	0	32	*x*
203	2	0	0	*y*	1	0	0	1	500			30.3	
204	13	12	10	0	10	3	10*y*					22.5	
205	8	1	0	0	2	*x*	0	2				45	
206	212	17	2	0	212	0	209	3	950			29	
207	5	2	0	0	2	0	2	0	750			46.5	
208	69	11	1	0	59	10	41*y*	18*y*	*y*	*y*	0	27	
209	349	33	0	0	74	0	40	34	*y*			20	
210									2,452			28	
211	1	1	1	0	1	0	1	0				24.5	
212				Included with Orange								35.8	
213	175	125	5	0	175	0	173	2	1,700			30.3	
214	21	13	5	0	21	0	*y*	*y*	*x*			21	
215		0	2						3,900			40–50	0.07
216	224	64	4	0	215	8	214*y*	1*y*	2,350		0	26.1	*y*
217									850			25.6	*y*
218	*y*	0	2	*y*	1	0	1	0				50	
219	2	0	0	2	0	0	0	0	850			30.3	

perforated in a basal Yegua sand from 6728 to 6734 ft. and completed as a distillate well, on Aug. 14, 1940. Three wells had previously been drilled in the area and no further drilling was done during the remainder of the year.

Lolita, Jackson County.—This appears to be the major discovery of the year and was opened by the completion of Wellington Oil Company's No. 1 L-Ranch for 335 bbl. from a Frio sand at 5933 to 5937 ft., on May 19, 1940. Rapid development in this field resulted in the discovery of two other producing horizons, at 5200 and 6400 ft., respectively. Magnolia, Shell and Humble are the principal leaseholders.

Mount Houston Gas Field, Harris County. Jack Frazier and Bunte Production Company's No. 1 Lena Griffith was completed for a Miocene gas well from 3482 to 3486 ft. on Aug. 26, 1940. The field is now inactive.

North Keeran, Victoria County.—Barnsdall No. 1 "A" Keeran was completed as a 55-bbl. well from a Frio sand from 5550 to 5552 ft. on Jan. 3, 1940. This appears to be a small field.

TABLE 1.—(*Continued*)

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
188	Miocene	Mio	S	Por	4,300	4,500	10	Ds	Mid-Olig	7,624
189	Frio	Olig	S	Por	7,604	7,618	14	?	Frio	9,335
190	Heterostegina, Marginulina, Frio	Olig	S	25±	2,900	3,800	80	Ds	Saline Bayou	7,521
191	Catahoula, Frio	Mio, Olig	S	Por	2,525	3,600	*y*	Df	Cook Mountain	7,666
192	Vicksburg	Olig	S	Por	5,274	5,282	*y*	?	Vicksburg	5,610
193	Frio	Olig	S	Por	5,686	5,770	10	Ds	Vicksburg	8,724
194	Wilcox	Eoc	S	14–43	7,855	7,922	18	?	Wilcox	8,518
195	Miocene, Marginulina, Frio	Mio, Olig	S	25	3,050	5,409	80	D	Vicksburg	9,001
196	Vicksburg	Olig	S	25	7,700	7,800	100	D	Vicksburg	9,001
197	Frio	Olig	S	Por	5,875	5,890	10	*y*	Frio	7,010
198	Cockfield, Yegua	Eoc	S	25*x*	5,375	5,575	10	DF	Wilcox	8,948
199	Frio	Olig	S	Por	5,176	5,948	100	ALf	Frio	8,174
200	Jackson, Pettus, Yegua, Wilcox	Eoc	SH	Por	3,065	7,535	11+	DF	Wilcox	7,921
201	Cockfield (Pettus)	Eoc	SH	Por	3,564	3,590	26	DF	Cockfield	3,598
202	Marginulina, Frio	Olig	S	30	6,600	6,608	8	T	Vicksburg	8,530
203	Frio	Olig	SH	Por	5,000	5,700	8	DF	Vicksburg	8,527
204	Catahoula, Frio, Vicksburg	Mio, Olig	S	Por	2,551 3,035 4,776	2,555 3,094 4,781	10	NLf	Vicksburg	5,252
205	Cockfield (Pettus)	Eoc	S	Por	3,985	4,017	5*y*	NF	Upper Yegua	4,306
206	Frio	Olig	S	30	5,480	6,050	150	Df	Frio	8,455
207	Yegua, Cook Mt.	Eoc	SH	Por	4,802 5,300	4,812 5,310	7	MCL	Cook Mountain	5,313
208	Miocene, Oligocene	Mio, Olig	S	30	4,560	6,756	10–20	Df	Vicksburg	8,501
209	Pliocene, Miocene, Mid-Oligocene	Pli, Mio, Olig	S	Por	354	*y*	250±	Ds	Vicksburg	7,000
210	Frio, Vicksburg	Olig	S	Por	5,200	5,784	100	Ds	Vicksburg	7,000
211	Frio	Olig	S	Por	5,204	5,220	16		Vicksburg	6,604
212	Frio	Olig	S	Por	5,585	6,123	8	D	Frio	7,550
213	Frio	Olig	S	28.4	5,086	5,780	40	Ds	Vicksburg	8,527
214	Jackson	Eoc	S	Por	1,280 1,389	1,302 1,440	7	MLf	Jackson	1,785
215	Frio	Olig	S	25	8,346 8,650	8,490 8,860	10	D	Frio	9,055
216	Marginulina, Frio	Olig	S	Por	5,470	5,560	50	Df	Vicksburg	9,200
217	Marginulina	Olig	S	Por	5,540	5,550	8	Df	Vicksburg	9,200
218	Frio	Olig	S	Por	7,903	10,058	25	N	Frio	10,796
219	Cockfield (Pettus)	Eoc	SH	Por		3,407	5	D	Pettus	3,708

Rowan, Brazoria County.—Rowan and Nichols' No. 1 T. B. Hubbard was completed for 187 bbl. of oil from a Frio sand from 8538 to 8554 ft., on June 30, 1940. In October production was also obtained from a horizon at 9000 ft., and the field is being developed. It appears to have been defined on the west and south.

Shepherd, San Jacinto County.—Harrison and Abercrombie's No. 1 Sun Company Fee was completed for 77 bbl. of oil from a Wilcox sand from 8215 to 8277 ft., on Sept. 20, 1940. Development is proceeding slowly and no statement regarding the importance of the find can be made at this time. This was the third attempt of Harrison and Abercrombie to develop production in the area.

Sheridan, Colorado County.—Shell Oil Corporation's No. 1 Plow Realty Co. was completed for 158 bbl. of 34.5° gravity oil from a Wilcox sand from 8138 to 8143 ft.,

TABLE 2.—*Summary of Drilling Operations in Texas Gulf Coast*

Important Wildcats Drilled in 1940

	County	Survey	Total Depth, Ft.	Surface Formation	Deepest Horizon Tested
1	Aransas	R. D. Blassman 196	9,335	Beaumont	Frio
2	Aransas	R. D. Blassman	8,406	Beaumont	Frio
3	Brazoria	Samuel Carter	11,860	Beaumont	Frio
4	Brazoria	Chas. Breen	11,085	Beaumont	
5	Brazoria	William Harris	10,010	Beaumont	Frio
6	Calhoun	Eusebio Hidalgo	10,002		Frio
7	Chambers	D. L. Broussard, sec. 82	8,865	Beaumont	Frio
8	Chambers	Trinity Bay	9,005	Beaumont	Frio
9	Chambers	Sect. 247 Trinity Bay	9,448	Beaumont	Frio
10	Chambers	Sect. 246 Trinity Bay	9,851	Beaumont	Frio
11	Chambers	Sect. 248 Trinity Bay	10,491	Beaumont	Frio
12	Colorado	O. K. Winn	8,339		Wilcox
13	Dewitt	Chas. Lockhart	8,518		Wilcox
14	Galveston	Asa Brigham	9,197		Frio
15	Galveston	Sarah White	7,100		
16	Galveston	Sarah White	6,872		
17	Galveston	Sarah White	7,056		
18	Harris	Jackson Bundick	4,915		Frio
19	Harris	John C. Ogburn	7,245		Cockfield
20	Harris	John C. Ogburn	7,250		Cockfield
21	Harris	Adam Smith	4,205		Mio
22	Jackson	I. & G. N. RR. No. 11	5,938		Frio
23	Jackson	I. & G. N. RR. No. 11	6,399		Frio
24	Jackson	S. F. Austin	5,278		Frio
25	Jackson	Wm. Menefee	6,604		Frio
26	Jackson	V. Garcia	6,002		Frio
27	Jackson	Ramon Muusquis	8,528		Frio
28	Jefferson	Joseph Probarth	8,296		Frio
29	Jefferson	B. Blackman	7,450		Frio
30	Liberty	Davis L. Kokernun	7,656		
31	Live Oak	L. A. Fant No. 20	8,386		Wilcox
32	Matagorda	Sect. 1 I. & G. N. RR.	8,971		Frio
33	Refugio	James Fagan	6,715		Frio
34	Refugio	Michael Reiley	6,509		Miocene
35	San Jacinto	William Hays	8,590		Wilcox
36	Victoria	Desiderio Nira	6,265		Frio
37	Victoria	Eugenie Benavides	6,373		Frio
38	Victoria	Maria Josefa Traviesa	6,076		Frio
39	Victoria	Foster Lewers	6,450		Frio
40	Victoria	Chas. M. Creamer	6,881		Frio
41	Victoria	Chas. M. Creamer	6,513		Frio
42	Victoria	Francisco Perez	6,506		Frio
43	Victoria	Martin de Leon	7,509		Vicksburg
44	Victoria	John B. Sideck	5,610		Vicksburg
45	Wharton	J. Scott	8,461		Cook Mt.
46	Wharton	Eucled M. Cox	5,500		Frio
47	Wharton	Sect. 25 G. H. & H. RR.	10,116		Wilcox

on May 27, 1940. Two other wells were completed in the area by Shell before the end of 1940.

Smith Point, Chambers County.—Humble Oil and Refining Company's No. 1 "A" State, sec. 247, was completed as a gas and distillate well from a Frio sand from 8796 to 8812 ft. on Aug. 18, 1940. Rapid development resulted in the discovery of another distillate horizon at 9400 ft. and the completion of an oil well at 10,327 to 10,343 ft. by the Humble Oil and Refining Co. in No. 3 "A." The structure appears to be a deep-seated faulted dome and results to date have been disappointing.

St. Charles, Aransas County.—Continental Oil Company's No. 1 St. Charles Land Co. blew out on Feb. 17, 1940, at 9327 ft. in a Frio sand. Well No. 2 was completed for 29 bbl. from 7637 to 7645 ft. and a third well is now drilling.

Terrell, Victoria County.—Colton and Colton's No. 1 E. H. Terrell was completed from a Vicksburg sand at 5274 to

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	Continental Oil Co.	Dist.	Blew Out				Discovery, St. Charles
2	Continental Oil Co.	48		¼	1,350	1,300	New sand, St. Charles
3	Glenn H. McCarthy	Dist.	240,000	9/64	Sealed	375	Discovery, Bailey's Prairie
4	Sun Oil Co.	120 dist.		¼	1,400	2,900	New sand, old ocean
5	Rowan & Nichols	187		⅛	1,725	1,550	Discovery, Rowan
6	Coronado Oil Co.	60		⅛	2,325	1,950	Discovery, Duck bay
7	Sun Oil Co.	84		⅛	3,200	2,500	Discovery, Fig Ridge
8	Humble O. & R. Co.	144		⅛	200	2,520	Discovery, Fisher's Reef
9	Humble O. & R. Co.	17 dist.		⅛		2,900	Discovery, Smith Point
10	Humble O. & R. Co.	228 dist.		¼		3,150	New sand, Smith Point
11	Humble O. & R. Co.	156		⅛		1,725	New sand, Smith Point
12	Shell Oil Co.	158		⅛	1,950	1,200	Discovery, Sheridan
13	Atlantic Ref. Co.		3,170,000	¼	2,650	2,450	Discovery, Thomaston
14	Stanolind O. & G. Co.	276		⅛	150	2,975	Discovery, Alta Loma
15	Sun Oil Co.	311		¼	2,300	1,875	New sand, Greer's Lake
16	Sun Oil Co.	214		3/16	None	125	New sand, Greer's Lake
17	Sun Oil Co.	355		¼	240	680	New sand, Greer's Lake
18	Cockburn H. C.	240		3/16	500	475	Discovery, Dyersdale
19	Joyce Richardson	27 dist.		¼	2,500	630	Discovery, Richardson
20	Joyce Richardson	37 dist.		⅛	2,275	2,025	New sand, Richardson
21	Jack Frazier Bunte Prod. Co.	None	850,000	¼	350	350	Discovery, Mt. Houston
22	Wellington Oil Co.	335		3/16	1,175	900	Discovery, Lolita
23	Magnolia Pet. Co.	201		⅛	1,250	1,050	New sand, Lolita
24	Magnolia Pet. Co.	269		11/64	750	650	New sand, Lolita
25	Pure Oil Co.	230			800	1,294	Discovery, W. Ganado
26	W. S. Boyle et al.	547		¼	980	750	New sand, W. Ranch
27	Magnolia Petr. Co.	617		¼	1,150	1,090	New sand, W. Ranch
28	Gulf Oil Corp.	848		¼	1,500	1,300	New sand, Fannett
29	Broussard & Hebert	249	14,230	¼		225	New sand, La Belle
30	General Crude Oil Co.	668		¼	650	825	New sand Esperson
31	E. M. Jones	Dist.		⅛			Discovery, Geo. West
32	The Texas Co.	29 dist.	200,000,000	⅛		2,950	Discovery, Blessings
33	Norsworthy et al.	80		3/32	2,300	1,160	Discovery, Fagan
34	Norsworthy et al.		Gas		995	995	New sand, Fagan
35	Harrison & Abercrombie	50 dist.	5,000,000		Sealed	1,850	Discovery, Shepherd
36	Titanic Oil Co.		Gas		2,050	2,050	Discovery, Edwards Ranch
37	Stanolind O. & G.	51		19/64	400	2,400	New sand, E. Placedo
38	Humble O. & R. Co.		Gas		2,000	1,800	New sand, McFaddin
39	Transwestern Oil Co.	81		3/32	290	650	New sand, McFaddin
40	Texas Gulf Prod. Co.	15		3/16	Sealed	75	Discovery, Bloomington
41	Texas Gulf Prod. Co.	90		7/64	1,500	500	New sand, Bloomington
42	Texas Gulf Prod. Co.	12 dist.		¼	2,100	2,050	New sand, Bloomington
43	Barnsdall Oil Co.	45		¼ top ¾ bot.	2,200	250	Discovery, N. Keeran
44	Colton & Colton	35			325	65	Discovery, Terrell
45	Cockburn Oil Corp.	11 dist.	2,500,000	7/64	3,450	950	Discovery, E. Bernard
46	J. F. Hutchins	108		⅛	Sealed	600	Discovery, Borden
47	Gulfboard Oil Corp.	24	850,000	5/32	Sealed	2,250	Discovery, Lissie

5282 ft. for 25 bbl. of distillate on Aug. 7, 1940. The field is now inactive.

Thomaston, Dewitt County.—Atlantic Refining Company's No. 1 Mrs. Pearl Conwell was completed as a distillate well in the Wilcox at 7855 to 7885 ft. on April 15, 1940. Several other wells have been completed but the field does not appear at this time to be important.

West Ganado, Jackson County.—Pure Oil Company's No. 1 F. Spacek was completed for 230 bbl. of 24.1° gravity oil from a Frio sand on Oct. 26, 1940, through perforations from 5204 to 5220 ft. One dry hole has since been drilled. Several producing horizons were encountered in the No. 1 Spacek but only one has been opened to production.

New Sands

Fannett, Jefferson County.—The discovery of production in the Frio section on the northwest flank of Fannett dome, Jefferson County, by the Gulf Oil Corporation in No. 2 Bordages, at 8296 ft., inaugurated a drilling campaign at this old dome which has resulted in the addition of substantial reserves. The entire area is controlled by the Gulf Oil Corporation and orderly development is in progress. The discovery well was completed on Jan. 25, 1940, for 846 bbl. of 36.4° gravity oil on a ¼ × 6 positive choke.

Esperson, Liberty County.—The Esperson dome, Liberty County, was actively explored by the General Crude Oil Co. and additional reserves are being developed. This area is controlled by the General Crude Oil Co.

West Ranch, Jackson County.—The active development in this field during 1940, because of diversified ownership, added to the reserves of the area.

Lolita Field, Jackson County.—This new field appears to be of major importance, owing to extensions and new sands found during the year, and will be quickly drilled by numerous owners.

Other Areas.—New sands were discovered at Keeran and McFaddin, Victoria County, and at Chocolate Bayou and Rowan, Brazoria County.

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Oil and Gas Development and Production in North Texas for the Year 1940

By Lewis W. MacNaughton,* Member A.I.M.E.

The North Texas district, as herein defined, includes the counties of Archer, Baylor, Clay, Cooke, Foard, Hardeman, Knox, Montague, Wichita, and Wilbarger. This area covers generally the crest and south flank of a system of buried mountains known as the Red River uplift. The oil and gas accumulations along this feature are in traps, which, although localized by structures incident to the regional uplift, are usually modified by stratigraphic changes in the sediments. Excepting the fields in southeastern Baylor, southern Archer, and southwestern Clay Counties, all the fields within the district are on this Red River uplift. These exceptions, which have the same type of oil and gas accumulation as the other fields, are on the extreme north end of the Bend arch, which is a broad anticline plunging northward from the Llano uplift in central Texas to Archer County. The larger part of past oil and gas production has come from Pennsylvanian strata, with less important amounts from the Permian, and minor but increasingly important quantities from the Ordovician.

Developments during 1940

The encouraging outcome of exploration and development in Montague and Cooke Counties and generally greater activity throughout the district resulted in the drilling of some 1700 wells during 1940, about 350 more wells than were drilled in 1939. Approximately 1250 of these tests were completed as oil wells.

Production likewise increased during 1940 to the extent of 8 million barrels more than the 25½ million barrels produced in 1939. In spite of this large increase in production, known oil reserves again increased substantially.

As is usually characteristic of this district, the new reserves were from a large number of fields, none of which were of such magnitude as to be important to the oil industry. Nevertheless, the Fargo field, Wilbarger County, deserves mention as one of the more important discoveries in this district during 1940. Following seismic surveys, the Amerada Petroleum Corporation located its No. 1 Goodpasture in sec. 35, block 15, H. and T. C. R. R. Co. survey, and drilled it to a total depth of 6717 ft. This well was completed in July 1940 through perforations in the casing from a pay between 3230 and 3252 ft. for an initial production of 241.5 bbl. on an 8-hr. pumping test. Other potential producing horizons were found in the Pennsylvanian at depths of 3960 to 3995 ft., 4208 to 4234 ft., 4407 to 4422 ft., and in the Ordovician at 6300 ft. Wells completed to date in the several Pennsylvanian horizons have an average daily potential of 600 bbl. of oil. Although no wells have yet been completed in the Ellenburger dolomite (Ordovician), the discovery well swabbed 15 bbl. per hour from this formation before plugging back for completion in an upper horizon.

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TABLE 1.—*Oil and Gas Production in North Texas*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
	Archer County:															
1	Blewitt	1940	80	0	14,186	14,186	0	0	10	10	0	0	10	0	0	10
2	Carson	1939	30	0	8,170	2,763	0	0	4	0	0	0	3	0	0	3
3	Chalk Hill (deep)	1931	600	0	2,976,441	186,998	0	0	41	0	2	0	39	0	32	7
4	Colgan	1939	80	0	20,193	19,823	0	0	10	4	0	0	9	0	0	9
5	Coleman	1940	20	0	1,873	1,873	0	0	1	1	0	0	1	0	1	0
6	Frarley	1939	30	0	5,627	2,550	0	0	3	1	0	0	3	0	0	3
7	Griffin	1939	250	0	62,087	31,643	0	0	7	1	0	0	7	0	*y*	*y*
8	Hull-Silk	1938	7,500	0	3,161,432	2,725,543	0	0	389	296	*y*	0	382	0	322	60
9	Mankins	1939	500	0	133,121	113,865	0	0	13	10	0	0	13	0	10	3
10	McCrory	1938	20	0	26,011	8,212	0	0	1	0	0	0	1	0	0	1
11	Meade	1940	30	0	683	683	0	0	3	3	0	0	3	0	0	3
12	Morrison	1939	30	0	8,319	5,970	0	0	3	1	0	0	3	0	0	3
13	Scotland	1938	20	0	13,457	5,949	0	0	1	0	0	0	1	0	0	1
14	Vogtsberger	1940	80	0	12,391	12,391	0	0	2	2	0	0	2	0	2	0
15	Woody	1940	10	0	329	329	0	0	1	1	0	0	1	0	0	1
16	All other fields		*y*	*y*	116,353,219	3,090,743	*x*	*x*	695*y*	101	*y*	*y*	3,607	*y*	12	3,595
	Total Archer County				122,797,539	6,223,521				431						
	Baylor County:															
17	Portwood	1924	600	*y*	4,613,963	247,055	0	0	188	0	13	*y*	147	0	0	*y*
18	Rendham	1940	250	*y*	13,887	13,887	0	0	3	3	0	0	3	0	0	4
19	Seymour	1939	1,000	*y*	216,773	180,004	0	0	20	10	0	0	17	0	0	17
	Clay County:															
20	Burns	1939	160	*y*	101,128	65,227	0	0	3	1	0	0	3	0	3	0
21	Costley	1939	20	*y*	36,174	34,533	0	0	10	7	0	0	10	0	*y*	*y*
22	Costley South	1940	50	*y*	11,629	11,629			13	13	0	0	13	0	0	13
23	Glasgow	1940	50	*y*	12,832	12,832	0	0	14	14	0	0	14	0	0	14
24	Halsell	1939	400	*y*	73,309	62,178	0	0	9	7	0	0	9	0	9	0
25	Hapgood	1940	120	*y*	18,513	18,513	0	0	3	3	0	0	3	0	3	0
26	Henderson	1939	310	*y*	45,237	45,237	0	0	15	14	0	0	14	0	13	1
27	Howard	1940	40	*y*	3,786	3,786	0	0	1	1	0	0	1	0	0	1
28	Jolly	1939	120	0	22,645	21,711	0	0	3	2	0	0	3	0	3	0
29	Kinder	1939	40	0	5,148	4,005	0	0	1	0	0	0	1	0	0	1
30	McInness	1940	60	0	49,515	49,515	0	0	15	15	0	0	15	0	0	15
31	Worsham	1937	200	0	442,974	50,770	0	0	14	1	0	0	7	0	*y*	*y*
32	All other fields		*y*	*y*	8,470,913	610,081			*y*	27					0	705
	Total Clay County				9,293,803	990,017			*y*	105						
	Cooke County:															
33	Callisburg	*y*	20	*y*	16,029	2,747	0	0	1	0	0	0	1	0	0	1
34	Gainsville	1935	550	0	3,173,041	362,039	0	0	*y*	*y*	*y*		123	0	*y*	*y*
35	T.C.U	1939	150	0	26,089	23,253	0	0	28	26	0	0	28	0	*y*	*y*
36	Voth	1938	500	20	252,454	87,512	*y*	*y*	38	14	0	0	28	2	2	28
37	Walnut Bend	1938	1,150	0	1,554,236	1,268,591	0	0	89	59	0	0	89	0	23	66
38	All other fields		*y*	*y*	15,069,869	1,181,520	*y*	*y*	*y*	*y*	*y*	*y*	932	*y*	1	932
	Total Cooke County				20,091,718	2,925,662			*y*	*y*			*y*			
	Foard County:															
39	Allee	1940	120	*y*	8,821	8,821	*y*	*y*	5	5	0	0	5	*y*	0	5
40	Johnson	1933	380	160	1,508,325	144,894	*y*	*y*	16	1	0	0	11	4	1	10
41	Thalia	1927	180	*y*	316,206	12,753	0	0	13	*y*	*y*	0	4	*y*	1	3

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	x	x		38	y	Swastika	Pen	S	Por	y	1,460	y	ML	Cisco	1,460
2	x	x		40	y	Gunsight	Pen	S	Por	1,490	1,510	3	y	y	y
3	900	y	PP	42	y	Canyon and Strawn	Pen	S	Por	2,200	2,225	20	A	Strawn	5,748
4	x	x		40	y	Gunsight	Pen	S	Por	1,453	1,461	8	y	Cisco	1,461
5	x	x		41	y	Bend	Pen	L	Por	5,009	5,058	19	y	Bend	5,058
6	x	x		40	y	Gunsight	Pen	S	Por	920	925	4	y	Gunsight	925
7	x	x		42	y	Gunsight	Pen	S	Por	1,630	1,640	8	y	Strawn	4,439
						Strawn	Pen	S	Por	4,390	4,410	24			
8	y	y		42–44	y	Cisco	Pen	S	Por	1,300	1,320	5	A	y	
						Upper Strawn	Pen	L	Por	3,800	3,860	15			
						Lower Strawn	Pen	S	Por	4,320	4,350	30			
						Basal Strawn	Pen	L	Por	4,545	4,563	18			
						Bend lime	Pen	L	Por	4,620	4,630	10			
9	x	x		43	y	Bend lime	Pen	L	Por	4,660	4,690	30	y	Bend	4,696
10	x	x		41	y	Bend lime	Pen	L	Por	4,735	4,760	20	y	Bend	4,760
11	x	x		38	y	Cisco	Pen	S	Por	y	960	y	y	Cisco	1,605
12	x	x		38	y	Gunsight	Pen	S	Por	1,290	1,300	4	y	Gunsight	1,300
13	x	x		y	y	Strawn	Pen	S	Por	4,135	4,138	3	y	Strawn	4,138
14	x	x		41	y	Strawn	Pen	S	Por	4,656	4,671	15	A	Ellenburger	5,335
15	x	x		37	y	Cisco	Pen	S	Por	1,393	1,399	6	y	Cisco	1,399
16															
17	x	x		36.5	y	Gunsight	Pen	S	Por	1,400	y	10	y	Strawn	4,265
18	x	x		31	y	Canyon	Pen	L	Por	3,061	3,094	y	y	Strawn	4,304
19	x	x		y	y	U. Canyon	Pen	L	Por	2,580	2,605	20	y	y	5,598
20	x	x		44	y	Strawn	Pen	S	Por	4,425	4,450	20	y	y	6,014
21	x	x		41	y	Cisco	Pen	S	Por	1,035	1,050	18	y	Cisco	1,275
				38						1,150	1,160				
22	x	x		y	y	Cisco	Pen	S	Por	y	1,143	5	y	Cisco	1,395
23	x	x		y	y	Cisco	Pen	S	Por	y	y		y	Cisco	1,912
24	x	x		38	y	Strawn	Pen	S	Por	4,750	4,790	y	y	Strawn	4,793
25	x	x		47	y	Bend	Pen	L	Por	5,972	5,994	20	y	Bend	6,538
26	x	x		40	y	Strawn	Pen	S	Por	3,yyy	3,yyy	y	y	Strawn	3,655
27	x	x		44	y	Bend	Pen	L	Por	5,460	5,488	15	y	Bend	5,488
28	x	x		41	y	Bend	Pen	L	Por	5,350	5,400	40	y	Bend	5,443
29	x	x		37	y	Strawn	Pen	S	Por	4,130	4,150	15	y	Bend	5,527
30	x	x		y	y	Cisco	Pen	S	Por	y	250	10	y	Cisco	y
										1,074	1,090				
31	x	x		38	y	Strawn	Pen	S	Por	3,400	3,440	10	y	Strawn	y
										3,900	3,950	26			
32															
33	x	x		47	y	y	Pen	y	y	3,519	3,521	2	y	y	3,775
34	x	x		41	y	y	y	y	y	y	y	y	y	y	y
35	x	x		30	y	y	Pen	y		1,125	1,140	15	A	y	y
36	x	x		38.9	y	Ellenburger	Ord	S	Por	1,620	1,630	10	y	Ellenburger	1,793
								L	Por	1,725	1,735	15			
37	x	x		34	y	Strawn	Pen	S		4,900	4,970	y	y	Cam-Ord	6,055
						Strawn	Pen	S		4,108	4,130				
						Simpson	Ord	y	y	5,200	5,240				
38															
39	x	x		33	y	Canyon	Pen	L	Por	2,360	2,370	10		Canyon	2,370
40	y	y		50	y	Canyon	Pen	L	Por	3,600	3,625	y		Pre-Cam	5,003
41	y	y		39	y	Thalia	Pen	S	Por	y	y	y		Pre-Cam	2,550
						Cisco	Pen	L	Por	2,500	2,550				

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940	
										During 1940		End of 1940			Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift
	Montague County:															
42	Benton and Holmes	1939	640	0	132,874	104,666	0	0	16	9	0	0	12	0	7	5
43	Bonita	1940	320	0	152,821	152,821	0	0	17	14	0	0	17	0	15	2
44	Bowie	1940	40	0	10,138	10,138	0	0	1	1	0	0	1	0	1	0
45	Nocona Townsite	1939	640	0	707,687	624,141	0	0	35	26	0	0	35	0	28	7
46	Ringgold	1940	200	0	64,021	64,021	0	0	8	8	0	0	8	0	8	0
47	All other fields		y	y	31,772,641	1,710,069			1,084	10					0	931
	Total Montague County				32,840,182	2,665,856	0	0	1,161	68						
	Wichita County:															
48	K.M.A. (deep)	1931	27,500	y	25,407,836	11,414,132	y	y	1,481	311	y	y	1,481	y	1,177	304
49	George	1940	20	0	y	y	y	y	2	2	0	0	2	0	0	2
50	Jackson	1938	300	0	y	y	y	y	17	y	y	y	17	0	y	y
51	Oats	1940	20	0	y	y	y	y	6	6	0	0	6	0	0	6
52	State Hospital	1938	80	0	y	y	0	0	3	1	0	0	3	0	y	3
53	Underwood	1939	60	0	y	y	0	0	9	3	0	0	9	0	y	y
54	All other fields		y	y	315,918,756	5,010,548			y	99					3	6,094
	Total Witchita County				341,326,592	16,424,680			y							
	Wilbarger County:															
55	Castleberry	1938	200	0	285,016	165,430	y	y	25	5	y	y	23	0	y	y
56	Consolidated	1939	600	0	455,374	437,434	y	y	31	23	0	y	30	0	28	2
57	Fargo	1940	630	0	11,001	11,001	y	y	6	6	0	0	6	0	6	0
58	Phillips-King	1938	100	0	64,853	34,675	y	y	7	3	0	0	7	0	1	6
59	Pois-Schultz	1939	60	0	42,131	33,065	y	y	9	3	0	0	9	0	1	8
60	All other fields		y	y	71,616,833	2,644,744			y	25					10	1,559
	Total Wilbarger County				72,475,208	3,326,349			y	66						
61	Total North Texas District				605,503,017	33,163,499										

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]	Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
42	*y*	*y*		38 40	*y*	Canyon Upper Strawn Lower Strawn	Pen Pen Pen	L S S	Por Por Por	2,020 2,900 3,400	2,030 2,960 3,870	25 10 20	*y*	*y*	4,078
43	*x*	*x*		40	*y*	Bend	Pen	Do	Por	5,240 5,443	5,249 5,458	9 15	A	*y*	6,975
44	*x*	*x*		45	*y*	Bend	Pen	L	Por	6,016	6,050	34	*y*	Bend	6,050
45	*x*	*x*		43 43 40	*y*	Upper Strawn Lower Strawn Bend	Pen Pen Pen	S S L	Por Por Por	4,280 4,650 5,230	4,300 4,680 5,250	*y*	*y*	*y*	6,988
46	*x*	*x*		47 46	*y*	Bend	Pen	Do	Por	5,693 5,789	5,704 5,794	15 5	A	Bend	5,811
47															
48	2,*yyy*	92*y*		40 42	*y*	Strawn Ellenburger	Pen Ord	SL L	Por Por	3,500 4,352	4,000 4,389	25± 30	ML	*y*	*y*
49	*x*	*x*		*y*	*y*	Cisco	Pen	S	Por	1,451	1,469	*y*	*y*	*y*	*y*
50	*x*	*x*		*y*	*y*	Canyon	Pen	L	Por	2,600	2,630	10	*y*	*y*	*y*
51	*x*	*x*		*y*	*y*	Cisco	Pen	S	Por	1,313	1,328	*y*	*y*	*y*	*y*
52	*x*	*x*		42	*y*	Bend	Pen	L	Por	5,076 5,336	5,120 5,362	*y*	*y*	Ellenburger	5,418
53	*x*	*x*		40	*y*	Cisco	Pen	S	Por	1,200	1,210	6	*y*	Cisco	1,481
54															
55	*x*	*x*		36 37	*y*	Cisco Canyon	Pen	S S L	Por	2,170 2,640 3,190	2,190 2,650 3,210	9 9 15	*y*	*y*	3,750
56	*x*	*x*		40	*y*	U. Strawn L. Strawn	Pen	S S	Por	3,750 4,025	3,770 4,065	22 40	*y*	*y*	4,066
57	*x*	*x*		41	*y*	Cisco Canyon Strawn	Pen	S L S	Por	*y* 3,992 4,438	3,252 4,002 4,455	*y* 15 15	A	Ellenburger	6,717
58	*x*	*x*		36	*y*	Cisco Canyon	Pen	S L	Por Por	*y* 2,500	1,902 2,550	*y*		*y*	3,370
59	*x*	*x*		38	*y*	Cisco	Pen	S	Por	1,235 1,665 1,885	1,245 1,685 1,900	*y*		*y*	2,675
60															
61															

K.M.A. Pressure Maintenance

Following a meeting of the K.M.A. field operators called by John F. O'Donohoe in November 1939, to discuss ways and means of obtaining maximum benefit from a cooperative pressure-maintenance program, the K.M.A. Pressure Maintenance Association was organized and an office opened on Jan. 15, 1940.

During 1940 the number of input wells was increased from 45 to 78 and the volume of gas injected was increased from 23,005,000 cu. ft. per month to the December high of 197,660,000 cu. ft. for a total volume of 1,470,156,000 cu. ft. for the year. The average volume of gas delivered daily to each input well was 16,491 cu. ft. at the beginning of the year and 81,745 cu. ft. at the end of the year. In December, 246.9 cu. ft. of gas were being returned to the reservoir for each barrel of oil produced. It is planned to increase this volume in 1941 to about 450 cu. ft. per barrel of oil produced. New input wells are still being added to the system and ineffective wells are removed. Ultimate results from this program

Table 2.—*Summary of Drilling Operations in North Texas*

Discoveries, Extensions, and Important Wildcats Drilled during 1940

	Field	County	Drilled by	Well No. and Farm	Survey
1	Blewitt	Archer	L. T. Burns	First Nat. Bank, Olney No. 1	Sou. Pac. R. R. Co.
2	Hull-Silk	Archer	Chapman & McFarlin	Wilson No. 7-E	E. Hall
3	Hull-Silk	Archer	Peterson-McCarty	Wilson No. 36	J. T. O'Reilly
4	Woody	Archer	Young and Woody et al.	Robertson No. 1	V. L. Lewellyn
5	Coleman	Archer	Shell Oil Co., Inc.	Coleman No. 1	A.T.N.C.L.
6	Vogtsberger	Archer	Gant	Vogtsberger No. 1	German Em. Co.
7	Rendham	Baylor	Hall-Jordan	F. C. Green No. 1	H. & T. C.-J. E. Hix
8	Seymour	Baylor	British American	Turbeville No. 1	T. & N. O.
9	Hapgood	Clay	Norwood	Hapgood No. 1	Marion Co. Sch. L.
10	Henderson (3,500-ft. sand)	Clay	Shell	H. Henderson No. 1	T. E. & L. Co.
11	Henderson (3,200-ft. sand)	Clay	Shell	H. Henderson No. 3	T. E. & L. Co.
12	Howard	Clay	Horton & Wiggins	Howard No. 1	T. J. Belcher
13	Costley	Clay	Costley	W. J. McInness No. 1	Clark
14	Thornberry (Ext.)	Clay	Apache Oil Co.	Henderson No. 1	Clark
15	Muenster district	Cooke	Kingery (now Seits, Comegys)	Flusche No. 1	E. Reed
16	Walnut Bend (4,100-ft. sand)	Cooke	Sinclair-Prairie	Hudspeth No. 1	J. D. Henderson
17	Allee	Foard	Thomason Oil Co.	Gamble No. 1	H. & T. C.
18	Benton	Montague	Sinclair-Prairie	Benton No. 1	T. R. Jackson
19	Bonita	Montague	Sinclair-Prairie	Howard No. 1	W. Wallace
20	Bonita (lower pay)	Montague	Sinclair-Prairie	Howard No. 2	W. Wallace
21	Bowie	Montague	Owen and Hults	Tucker No. 1	T. E. & L. Co.
22	Ringgold	Montague	W. B. Omohundro	Seay No. 1	H. & T. C.
23	Sunset	Montague	Walter Gant	Laird No. 1	R. T. Millard
24	K.M.A. (deep pay)	Wichita	Fain-McGaha	Griffin No. 1-E	W. H. Spillers
25	Fargo	Wilbarger	Amerada Petr. Corp.	Goodpasture No. 1	H. & T. C.
26	Fargo (lower pay)	Wilbarger	Amerada Petr. Corp.	Parker No. 1	H. & T. C.
27	Fargo (lower pay)	Wilbarger	Amerada Petr. Corp.	Dodson No. 1	H. & T. C.
28	Harrold	Wilbarger	Big Six Oil Co.	Morris No. 1	H. & T. C.

cannot be estimated, but to date it has retarded the decline in bottom-hole pressure and has not increased gas-oil ratios.

Outlook for 1941

As mentioned last year, the collecting of accurate geological information becomes very important in regions like north Texas, where the oil and gas fields are partly controlled by stratigraphic conditions. Since such information is now being collected continually, it is believed that the prospects of finding additional reserves in 1941 are good. Firm demand and higher prices for crude oil also will furnish an incentive in this search for new fields.

Acknowledgments

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Table 2.—(*Continued*)

Discoveries, Extensions, and Important Wildcats Drilled during 1940

	Producing Formation	Depth Completed, Ft.	Total Depth, Ft.	Surface Formation	Initital Production per Day: Oil U. S. Bbl.	Initital Production per Day: Gas, Millions Cu. Ft.	Choke or Bean, Fractions of an Inch	Remarks
1	Swastika sand	1,460	1,468	Permian	10		Pumping	Ten producers, no dry hole
2	Bend lime	4,620–4,630	5,091	Permian	42 (1 hr.)		Flowing	Deeper pay, 4 prod., numerous dry holes
3	Strawn lime	4,545–4,563	4,563	Permian	623 (12 hr.)		Flowing	New pay
4	Swastika sand	1,393–1,399	1,399	Permian	20		Pumping	One well only
5	Bend lime	{5,009–5,014 5,042–5,058}	5,058	Permian	255 (3 hr.)	3	Flowing	Also Strawn show, D.S.T. 150 ft. oil-15 min.
6	Strawn sand	4,656–4,671	4,713	Permian	80 (2 hr.)		Flowing	Two prod., one dry hole
7	Canyon lime	3,061–3,064	3,064	Permian	184 (6 hr.)		Swabbing	Three prod., three dry holes
8	Canyon lime	2,514–2,522	2,522	Permian	336		Flowing	Extension
9	Bend lime	5,972–5,994	5,994	Pennsylvanian	262 (3 hr.)		Flowing	Three prod., one failure
10	Strawn sand	3,505–3,545	3,545	Permian-Penn.	338		Pumping	Two prod., no failures in 3500-ft. sand
11	Strawn sand	3,194–3,205	3,208	Permian-Penn.	165 (3 hr.)		Flowing	Ten prod., no failures in 3200-ft. sand
12	Bend lime	5,460–5,488	5,488	Permian	133		Pumping	No additional wells
13	Cisco sand	1,074–1,090	1,090	Permian	150		Pumping	Twelve pumpers, three dry holes
14	Cisco sand	1,130–1,136 ap.	1,141	Permian	15		Pumping	Three small pumpers, five dry holes
15	Canyon sand	1,000–1,006	1,013	Comanchean	76		Pumping	Two pumpers, two dry holes
16	Strawn sand	4,108–4,130	4,130	Comanchean	86 O. 57 W. (6 hr.)		Pumping	Two producers.
17	Canyon lime	2,360–2,370		Permian	39 O. 144 W. (23 hr.)		Flowing	Four small oil wells, one gas, no dry holes
18	Bend lime	5,126–5,135	5,137	Pennsylvanian	119		Flowing	Two producers, no failures
19	Bend lime	5,240–5,249	5,249	Comanchean	265 (3 hr.)		Flowing	Six producers, eleven failures
20	Bend lime	5,443–5,458	5,458	Comanchean	269 (3 hr.)		Flowing	Eight producers, five failures
21	Bend lime	6,016–6,050	6,050	Pennsylvanian	1,085 (12 hr.)		Flowing	Will make approx. 95 bbl. daily, natural
22	Bend lime	5,693–5,704	5,704	Pennsylvanian	240 (3 hr.)		Flowing	Six producers, three failures
23	Strawn sand	4,863–4,878	4,878	Pennsylvanian-Miss.	35 (12 hr.)		Swabbing	Still testing
24	Ellenburger dolo.	4,352–4,389	4,389	Permian	179 (19 hr.)		Flowing	Three producers, and approx. 12 failures
25	Cisco sand	3,200 approx.	3,252	Permian	241 (8 hr.)		Flowing	Three good wells, two failures in this zone
26	Strawn lime	4,438–4,455	4,476	Permian	33		Flowing	
27	Canyon sand	3,982–4,002	4,002	Permian	Being tested		Flowing	This zone also showed in discovery 1 mi. NW.
28	Cisco sand	2,895–2,904	2,907	Permian	Being tested		Pumping	Still testing

	In Proven Fields
Number of oil wells completed in 1940	1,250
Number of gas wells completed in 1940	3
Number of dry holes completed in 1940	500

Oil and Gas Production in North Central Texas for 1940

By H. W. Imholz*

A number of interesting wells were drilled in north central Texas during 1940. The Shell Oil Company's Smith well in sec. 143, block 1, H. and T. C. survey, Stonewall County, was completed for an initial production of 581 bbl. per day from the Mississippian limestone, with a total depth of 6065 ft. The same company's Patterson well, sec. 393, block D. H. and T. C. survey, Stonewall County, tested the Ellenburger limestone and was abandoned as a dry hole with a total depth of 6760 feet.

In Nolan County the Tex-Harvey Oil Co. drilled a well in sec. 43, near the Tipton well, which was completed as a small producer in the Strawn section. The Tex-Harvey well tested this producing horizon but was abandoned as a dry hole with a total depth of 5210 feet.

The Montour-Haggart well, sec. 184, block 2, H. and T. C. survey, Fisher County, tested the Strawn and was abandoned with a total depth of 5664 feet.

The Georgian Oil Company's Blach, sec. 309, T. R. and L., Shackelford County, encountered the top of the Ellenburger limestone at 4725 ft. After being plugged back to 3915 ft. from a total depth of 4825 ft., the well tested 10 bbl. of oil per day and 300 bbl. of water.

The W. I. Sothern No. 2 Carlisle well in sec. 293 was deepened to the Cambrian. The top of the Ellenburger was encountered at 6540 feet.

A wildcat well in Fisher County, the E. A. Stephenson-Maberry, apparently opened a new pool when the well encountered sand from 3298 to 3302 ft. and was completed for 50 bbl. per day in the Cook sand horizon.

In Jones County, the King Oil Company's Olsen well, sec. 158, B. B. B. and C. survey, extended the Avoca-Olander pool. The well was completed for 263 bbl. in 8½ hr. from the Palo Pinto limestone, from 3298 to 3302 ft. Ungren-Frazier extended the Akard pool with No. 1 Akard, in the D. T. Bruce survey. The well was completed for 83 bbl. per day from the Cook sand, encountered from 2109 to 2126 feet.

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* Consulting Geologist, Abilene, Texas.

TABLE 1.—*Oil and Gas Production in North Central Texas for* 1940

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres, Gas[b]	Total Oil Production, Bbl.	
				To End of 1940	During 1940
1	Bull Alcorn, *Brown*	1927	100	133,896	3,361
2	Byler, *Brown*	1926	290	856,270	11,931
3	Byrd, *Brown*	1920	250	405,880	3,070
4	Childress, *Brown*	1927	180	910,384	41,307
5	Clark-Buffalo, *Brown*	1927	460	806,924	15,478
6	Cross Cut, *Brown*	1921	2,300	6,327,664	94,488
7	Fry, *Brown*	1925	940	7,856,048	64,101
8	George, *Brown*	1927	200	810,834	26,803
9	Smith-Ellis, *Brown*	1926	450	2,345,284	45,226
10	Stover, *Brown*	1926	1,500	7,312,783	153,911
11	Others, *Brown*		5,595	2,569,862	61,853
12	Total *Brown County*		12,265	30,335,829	521,529
13	Baum, *Callahan*	1925	500	880,188	7,820
14	Hatchett, *Callahan*	1927	375	1,421,557	35,577
15	Isenhour, *Callahan*	1923	600	2,222,580	43,936
16	Moutray, *Callahan*	1926	400	2,568,579	68,046
17	Others, *Callahan*		9,515	7,426,080	228,917
18	Total *Callahan County*		11,390	14,518,984	384,296
	Burkett, *Coleman*				
19	Shallow	1924	850	2,390,569	70,665
20	Deep	1930	200	700,701	12,003
21	Dibrell, *Coleman*	1927	170	460,765	41,762
22	Eastland, *Coleman*	1928	270	2,069,407	34,519
23	Jennings, *Coleman*	1927	135	483,734	12,753
24	Overall, *Coleman*	1926	200	1,301,454	47,472
25	Sanata Anna, *Coleman*	1922	150	462,911	3,399
26	Stewardson, *Coleman*	1930	200	427,382	15,456
27	Others, *Coleman*		985	2,339,812	348,337
28	Total *Coleman County*			10,636,645	586,366
29	Others, *Comanche*			1,596,479	111,207
30	Desdemona, *Eastland, Erath*	1918	6,175	23,282,807	144,034
31	Hilburn, *Eastland*	1919	400	1,119,916	8,788
32	Mangum, *Eastland*	1922	300	901,566	24,276
33	Pioneer, *Eastland*	1919	1,400	5,566,654	59,225
34	Others, *Eastland*			66,884 474	712,990
35	Total *Eastland County*			74,472,610	805,279
36	Howard, *Fisher*	1934	40	93,235	12,937
37	Royston, *Fisher*	1928	2,800	10,728,497	540,189
38	Rotan (Robinson), *Fisher*	1936	640	1,028,488	224,146
39	Rotan (Bennett), *Fisher*	1937	80	51,707	16,023
40	Total *Fisher County*			11,955,827	793,295
41	Others, *Haskell*			178,531	17,515
42	Akard, *Jones*	1938	200	68,075	31,389
43	Avoca, Griffin, *Jones*	1938	640	1,221,825	607,384
44	Avoca, Olander, *Jones*	1936	640	1,356,861	423,740
45	Dorsey, Hawley, *Jones*	1935	600	3,030,764	137,410
46	Guitar, Hawley, *Jones*	1936	400	749,711	69,391
47	Irvin, Noodle Creek, *Jones*	1937	500	199,655	67,072
48	Jennings, *Jones*	1934	160	585,662	25,060
49	Lewis, *Jones*	1936	800	1,110,091	448,271
50	Noodle Creek, *Jones*	1927	1,030	6,879,138	190,278
51	Sayles, *Jones*	1932	640	1,761,439	359,053
52	Sandy Ridge, *Jones*	1935	450	305,397	31,670
53	Steffens, *Jones*	1937	640	364,588	230,198
54	Others, *Jones*			272,868	73,475
55	Total *Jones County*		6,700	17,906,174	2,694,391
56	Other, *Nolan*	1939	40	2,056	650
57	Bluff Creek, *Shackelford*	1930	940	3,312,943	256,595
58	Cook, *Shackelford*	1925	1,460	16,519,730	643,522
59	Frye, *Shackelford*	1925	115	330,658	9,026
60	Hope, *Shackelford*	1923	220	1,308,632	50,790
61	Ibex, *Shackelford*	1921	1,240	2,460,373	22,515
62	Ivy, *Shackelford*	1937	700	1,087,072	542,351
63	Newell, *Shackelford*	1925	640	873,581	51,862
64	Simmons-Harvey, *Shackelford*	1925	160	397,176	24,253
65	Tannehill, *Shackelford*	1927	300	2,436,810	115,361
66	Others, *Shackelford*			11,522,033	606,688
67	Total *Shackelford County*			40,249,008	2,322,963
68	*Stephens County*			127,179,655	896,715
69	*Stonewall County*			90,096	39,608
70	*Taylor County*			402,280	55,567
71	*Throckmorton County*			3,390,988	100,214

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE I.—(*Continued*)

Line Number	Number of Oil and/or Gas Wells, End of 1940	Character of Oil, Gravity A.P.I. at 60°F., Weighted Average	Producing Formation				
	Producing Oil[c]		Name	Age[e]	Character[f]	Depth, Avg. Ft. Top Prod. Zone	Structure[h]
1	11	38	Fry sand	Pen	S	1,150	ML, N
2	24	39	Fry sand	Pen	S	1,300	ML, N
3	10	37	Bend	Pen	L	2,450	A
4	112	35	Childress	Pen	S	800	ML, N
5	36	42	Fry sand	Pen	S	1,150	ML, N
6	149	40	Cross Cut sand	Pen	S	1,200	NL, M
7	100	42	Fry sand	Pen	S	1,300	ML, N
8	30	39	Fry sand	Pen	S	1,300	ML, N
9	37	41	Fry sand	Pen	S	1,300	ML, N
10	159	41	Blake sand	Pen	S	1,200	ML, N
11							
12							
13	15	39	Cross Plains sand	Pen	S	1,700	ML, N
14	94	38	Moutray sand	Pen	S	400	ML, N
15	136	37	Isenhour sand	Pen	S	700	ML, N
16	77	37	Moutray sand	Pen	S	750	ML, N
17	980						
18	1,302						
19	173	34	Burkett sand	Pen	S	400	M, L
20	19	41	Cross Cut sand	Pen	S	1,550	ML, N
21	14	42	Gwinnup sand	Pen	S	1,900	ML, N
22	28	42	Gwinnup sand	Pen	S	2,000	ML, N
23	26	39	Fry sand	Pen	S	1,950	ML, N
24	12	42	Strawn sand	Pen	S	2,300	A
25	10	39	Fry sand	Pen	S	1,500	ML, N
26	15	39	Fry sand	Pen	S	1,450	ML, N
27	50						
28							
29	138						
30	66		Desdemona	Pen	S	2,750	A
31	3	37	Bend	Pen	L	3,100	MN
32	35	38	Strawn	Pen	S	1,200	N
33	50	41	Caddo	Pen	L	2,450	AF
34	359						
35							
36				Pen	L	3,670	ML, N
37	117	39	Saddle Creek	Pen	L	3,100	A
38	35	38	Camp Colorado	Pen	L	3,500	MN
39	1	39	Camp Colorado	Pen	L	3,600	MN
40							
41							
42	11	39	Bluff Creek	Pen	S	3,200	MN
43	64	39	Strawn-Canyon	Pen	L	3,200	A
44	54	39	Strawn-Canyon	Pen	L		A
45	79	39	Six Cisco sands	Pen	S	1,900–2,300	A
46	67	37	Cook	Pen	L	2,000	A
47	10	39	Four Cisco sands	Pen	L, S	2,350–3,000	A
48	18	39	King sand	Pen	S	2,040	A
49	87	39	Bluff Creek	Pen	S	1,900	ML, N
50	83	38	Camp Colorado	Pen	L	2,500	MCA
51	50	41	Cook	Pen	S	1,950	N
52	21	37	Bluff Creek	Pen	S	1,900	N
53	30	37	Bluff Creek	Pen	S	1,900	ML, N
54							
55							
56	1	43	Strawn-Canyon	Pen	S	5,130	N
57	214	37	Bluff Creek sand	Pen	S	1,600	N
58	327	37	Cook sand	Pen	S	300	ML, N
59	38	35	Fry sand	Pen	S	450	ML, N
60	39	37	Hope sand	Pen	S	1,500	ML, N
61	17	39	Caddo	Pen	L	3,500	N
62	72	39	Strawn-Canyon	Pen	L	1,900–3,200	A
63	85	37	Tannehill sand	Pen	S	1,100	ML, N
64	19	39	Bluff Creek sand	Pen	S	1,700	N
65	84	38	Tannehill sand	Pen	S	1,150	ML, N
66							
67							
68							
69							
70							
71							

Oil and Gas Development in the Texas Panhandle for the Year 1940

By Henry Rogatz* and H. W. McCue†

Oil.—In the Texas Panhandle, 502 oil wells were drilled during the year 1940, with a total daily initial production of 139,187 bbl.—that is, 137 more oil wells drilled than in the previous year, with an increase in total daily initial production of 8219 bbl. The total daily potential of the field on Dec. 31, 1940, as determined by the Texas Railroad Commission, was 1,375,502 bbl., an increase of 30,825 bbl. over the previous year. On Dec. 31, 1940, a daily allowable of 85,050 bbl., which was a decrease of 35 per cent over 1939, was assigned to the field to be produced from 4788 wells. The total amount of oil produced for the year was 26,788,590 bbl., making a cumulative total of 378,960,728 bbl. during the past 19 years. No new oil-producing acreage was discovered.

Gas.—During the year, 92 gas wells were drilled, having a combined open flow of 2,402,900,000 cu. ft.; that is, 6 more than the number of wells drilled in 1939, with an increase in the open flow of 204,900,000 cu. ft. per day. The gas production for the year was 670,435,112,000 cu. ft., and the total gas removed from the ground during

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† Columbian Fuel Corporation, Amarillo, Texas.

Table 1.—*Oil and Gas Production in Texas Panhandle*

Line Number	County	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940
1	Carson	1921	19,570	247,194	35,592,308	3,122,257
2	Gray	1925	58,845	227,127	171,893,038	12,482,878
3	Hansford	1937		[1]		0
4	Hartley	1928	0	29,491		0
5	Hutchinson	1922	60,993	217,071	145,420,953	9,052,086
6	Moore	1926	640	432,130	4,966,679	258,211
7	Potter	1919	0	144,786	33,822	0
8	Sherman	1938	0	[1]	0	0
9	Wheeler	1925	8,250	153,768	18,845,678	1,873,158
10	Total		148,298	1,451,567	376,752,478	26,788,590

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Acreage not definite: for provisional figures see "New Developments," in text.

the past life of the field was about 9⅓ trillion cu. ft. No additional gas acreage was added to that listed in 1939.

Pipe-line Gas.—The pipe-line companies withdrew 263,781,196,000 cu. ft. of gas (a daily average of 720,713,000 cu. ft.). The total yearly withdrawals by pipe line increased 14,873,124,000 cu. ft. from those of 1939.

Natural Gasoline.—Throughout the greater part of the year, 38 gasoline-extraction plants processed 1,478,492,000 cu. ft. per day, a total of 541,128,283,000 cu. ft. for the year. This gas yielded 304,326,036 gal. of natural gasoline. The total daily capacity of all the plants is 2,434,400 thousand cubic feet.

Carbon Black.—Twenty-nine carbon-black plants operated during 1940, burning 294,314,675,000 cu. ft., or a daily amount of 804,138,000 cu. ft., and producing approximately 415,000,000 lb. of carbon black for the year.

Refineries.—Runs to the six operating refineries for the year 1940 amounted to 14,928,000 bbl.—a daily average of 40,786 bbl., or an increase of 1386 bbl. per day over 1939. At the end of the year only six refineries were still operating.

Storage.—The oil in storage decreased 572,942 bbl.; from 2,578,597 to 2,005,655 bbl. The total storage capacity at the end of the year was 15,560,500 barrels.

New Developments.—The Stinnett pool, in western Hutchinson County, was extended one mile west and gives promise of having a more productive formation than in the larger portion of the remainder of this pool. The extension should add about 500 acres to the proven area. An attempt was made to open up a new pool about 6 miles northwest of Stinnett, but the couple of fair producing wells brought in are a far cry from indicating a pool. No other new pools were opened, but the drilling of several marginal leases more clearly out-

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Character of Oil	
				During 1940		End of 1940			Number of Wells					
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	Gravity A.P.I at 60°F., Weighted Average	Sulphur, Per Cent
1			963	113	4	y	495	341	y	y	430	323	39	0.06
2			2,580	173	24	y	2,019	230	y	y	430	282	39	0.04
3			1	0	0	y		0	0	0	430	430		
4			4	0	0	y		4	0	0	430	410		
5			2,679	237	24	y	1,464	353	y	y	430	264	35	0.08
6			421	40	2	y	21	380	y	y	430	368	31	0.08
7			54	0	0	y		44	0	0	430	389	y	y
8			4	1	0	y		0	y	y	430	430		
9			768	21	6	y	368	343	y	y	430	241	37	0.04
10	9,367,256	670,435	7,474	585	60	y	4,367	1,695	y	y				

lined the already fairly well defined edges of the Panhandle oil field.

The ITIO Bryant No. 1 well was an unsuccessful attempt to uncover pre-Pennsylvanian production in the western end of the Anadarko Basin. This was the second well drilled on the ITIO structure in southwest Sherman County. The total depth was 5138 ft., ending in red granite after having penetrated approximately 300 ft. Mississippian and approximately 700 ft. Ordovician. The well was finally completed for 33 million cu. ft. of gas producing at the Permo-Pennsylvanian contact.

Wildcats.—Six wildcats were completed, none of which discovered oil or gas in commercial quantities. They were distributed as follows: Childress County, 1; Cottle County, 1; Hall, 1; Hansford, 1; Motley, 2. The total footage drilled was 35,387 feet.

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.[2] Top Prod. Zone	Depth, Avg. Ft.[2] Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	Big Lime series (Wichita)	Perm-Pen	D, DA LA							
	Granite wash (Cisco)	Pen	GW	x	3,000	3,040	40	AF	Granite wash (E zone)	y
2	Big Lime series (Wichita)	Perm-Pen	D, DA LA		3,100	3,150	50	AF		
	Granite wash (Cisco)	Pen	GW	x	2,850	2,880	30	AF	Granite wash (E zone)	y
3	Big Lime series (Wichita)	Perm-Pen	D, DA, LA							
	Granite wash (Cisco)	Pen	GW	x	x	x	x	AF	Big Lime series (Wichita	3,311
4	Big Lime series (Wichita)	Perm-Pen	D, DA LA							
	Granite wash (Cisco)	Pen	GW	x	x	x	x	AF	Granite wash (E zone)	y
5	Big Lime series (Wichita)	Perm-Pen	L	x	2,800–3,200	2,840–3,240	40	AF	Arbuckle	5,333
6	Big Lime series (Wichita)	Perm-Pen	D							
	Granite wash (Cisco)		GW	x	3,400	x	x	AF	Arbuckle	8,013
7	Big Lime series (Wichita)	Perm-Pen	D							
	Granite wash (Cisco)		GW	x	x	x	x	AF	Granite wash (E Zone)	y
8	Big Lime series (Wichita)	Perm-Pen	D	x	x	x	x	AF	Big Lime series (Wichita)	y
9	Big Lime series (Wichita)		D							
	Granite wash (Cisco) . .		GW	x	2,400	2,430	30	AF	Arbuckle	2,957
10										

[2] Depths refer to sands only.

Development along Fault Zone of South Central Texas in 1940

By William H. Spice, Jr.,* Member A.I.M.E.

The fault zone of south central Texas showed renewed activity during 1940 along a trend roughly paralleling the old established Balcones fault-line group of producing fields. This was a result of the new discoveries in the Wilcox (Eocene) formation in southeastern Texas and Louisiana. As of the end of the year, one new field producing from the Wilcox formation had been discovered on the Washburn ranch in La Salle County, along the southwestern limits of the district, and several projected tests into that formation were under way.

In the western part of the district, particularly in the part of the Rio Grande embayment that is in Dimmit, Webb and Zavala Counties, there has been renewed leasing activity with the shallower sands in the Navarro-Taylor formations (Upper Cretaceous) as the objective in several projected tests for the early part of 1941.

Three new fields have been discovered along the old fault-line trend, but these have been comparatively small, producing either from Dale lime, Austin chalk or Buda lime. No new fields were discovered during the year in the Edwards (Lower Cretaceous) lime horizon.

Approximately 260 wells were drilled in the district during 1940, which resulted in four new oil fields. Twenty-seven new wells were completed in the proven Edwards lime fields of Darst Creek, Luling and Salt Flat and seven were added to production in the Pearsall field. Approximately 160 wells in 18 counties were completed as failures during the year.

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* Consulting Geologist, San Antonio, Texas.

The district produced 7,659,634 bbl. during 1940, which was a 9 per cent decrease under production for 1939. In all, 3559 wells were producing at the end of 1940, compared with 3562 wells producing at the end of the previous year; 104 new producing wells were completed and 163 wells were abandoned in the producing fields of the district.

During 1940 considerable exploratory work was carried on along the Wilcox trend within the district, particularly by major companies employing various types of geophysical methods, and leasing activity increased considerably. At the end of the year, the total number of acres of nonproducing leases held by major companies in the district increased about 10 per cent. It is anticipated that this activity will continue into the first part of 1941 and will be supplemented by several exploratory test wells.

New Fields

Bee Creek, Caldwell County.—R. R. Ogden No. 2 Talley, discovery well of the Bee Creek field, in the northeastern part of Caldwell County, was completed on March 16, 1940, in Dale lime from 2091 to 2238 ft., pumping 85 bbl. per day, 39° A.P.I. gravity. The discovery of this field can be credited to a combination of subsurface geology and magnetometer work, which indicated the presence of a serpentine intrusion. At the end of the year, 13 producing oil wells had been completed and the field has produced a total of 47,050 barrels.

TABLE 1.—*Oil and Gas Production in Fault Zone of South Central Texas*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift
1	Alta Vista, *Bexar*	1912	300	0	120,756	5,989		37	0	2	0	33	0	0	33
2	Bee Creek, *Caldwell*	1940	160	0	47,050	47,050		16	13	3	0	13	0	2	11
3	Branyon, *Caldwell*	1930	900	0	2,485,066	346,520		185	1	7	2	151	0	0	151
4	Buchanan, *Caldwell*	1928	250	0	402,280	33,142		41	0	10	1	28	0	0	28
5	Burdette Wells, *Caldwell*	1936	200	0	57,117	3,646		12	0	4	1	2	0	0	2
6	Byersville, *Williamson*	1933	370	0	524,815	27,169		47	1	4	0	36	0	0	36
7	Carroll, *Bastrop*	1932	100	0	101,547	4,926		9	0	1	0	7	0	0	7
8	Cedar Creek, *Bastrop*	1932	100	0	275,157	16,438		13	1	2	0	10	0	0	10
9	Chapman, *Williamson*	1928	450	0	4,288,033	67,568		70	0	0	1	69	0	0	69
10	Chicon Lake, *Medina*	1920	350	0	62,603	14,897		66	15	1	0	65	0	0	65
11	Chriesman, *Burleson*	1938	10	0	19,310	3,585		1	0	0	1	0	0	0	0
12	Dale, *Caldwell*	1927	260	0	1,470,546	58,274									
13	Dale, West, *Caldwell*	1937	240	0		18,339		55	1	3	1	51	0	0	51
14	Dale, North, *Caldwell*	1932	320	0		27,681		12	0	5	0	6	0	0	6
15	Darst Creek, *Guadalupe*	1928	1,920	0	48,709,001	2,135,594		357	12	13	0	345	0	9	336
16	Darst Creek Extension, *Guadalupe*	1935	200	0	365,731	31,322		11	0	0	0	8	0	0	8
17	Day Field, *Guadalupe*	1940	20	0	575	575		2	2	0	1	1	0	0	1
18	Dunlap, *Caldwell*	1930	120	0	341,667	18,567		14	0	0	1	10	0	0	10
19	Dunlay, *Medina*	1938	30	0	1,988	0		1	0	0	1	0	0	0	0
20	Eckert, *Bexar*	1927	850	0	881,968	34,609		121	0	11	0	108	0	0	108
21	Elm Creek, *Guadalupe*	1939	350	0	6,301	6,301		31	18	13	2	16	0	1	15
22	Gas Ridge, *Bexar*	1912	100	150	71,117	3,172	89	89	7	3	3	21	62	0	21
23	Hilbig, *Bastrop*	1932	260	0	1,551,476	72,109		12	0	0	0	12	0	12	0
24	Jones, *Bexar*	1921	20	0	2,151	505		3	0	0	0	3	0	0	3
25	Kimbro, *Travis*	1935	40	0	3,469	194		4	0	0	0	4	0	0	4
26	La Coste, *Bexar*	1939	40	10	2,905	920		5	1	0	2	1	0	0	1
27	Larremore, *Caldwell*	1927	80	0	324,860	17,762		13	0	1	0	12	0	0	12
28	Lone Oak, *Bexar*	1934	10	0	4,485	36		1	0	0	0	1	0	0	1
29	Lytton Springs, *Caldwell*	1925	1,360	0	8,489,053	104,949		157	0	13	4	139	0	0	139
30	Luling, *Caldwell, Guadalupe*	1921	2,200	15	74,899,894	2,345,353		606	6	7	5	583	3	0	583
31	Manda, *Travis*	1935	40	0	24,385	1,914		3	0	1	1	1	0	0	1
32	Manford, *Guadalupe*	1929	40	0	401,698	5,930		1	0	0	0	1	0	0	1
33	Minerva-Rockdale, *Milam*	1921	4,250	0	3,600,516	75,666		414	6	6	0	392	0	0	392
34	Nash Creek, *Guadalupe*	1936	10	0	46,535	352		1	0	0	1	0	0	0	0
35	Pearsall, *Frio*	1933	800	0	1,202,123	213,012		27	7	0	2	25	0	11	14
36	Philtop, *Bexar*	1938	40	0	6,583	2,885		8	0	1	3	3	0	0	3
37	Red Rock, *Bastrop*	1939[1]	35	0	2,169	0		3	0	3	0	0	0	0	0
38	Riddle, *Bastrop*	1938	50	0	61,115	16,824		7	0	2	3	2	0	0	2
39	Salt Flat, *Caldwell*	1928	1,300	0	41,265,198	1,555,291		298	9	6	12	278	0	2	276
40	Somerset, *Atascosa, Bexar*	1912	11,390	0	10,734,928	197,978		915	0	28	7	872	0	0	872
41	Southton-Yturria, *Bexar*	1921	650	0	653,538	18,091		103	0	6	0	94	0	0	94
42	Spiller, *Guadalupe*	1938	30	0	12,935	4,660		6	0	0	0	3	0	0	3
43	Taylor-Ina, *Medina*	1922	380	0	152,960	3,190		16	1	0	1	7	0	0	7
44	Tenney Creek, *Caldwell*	1940	10	0	4,188	4,188		2	2	0	0	2	0	2	0
45	Thrall, *Williamson*	1914	475	0	2,460,426	28,098		27	0	5	1	19	0	0	19
46	Walnut Creek, *Caldwell*	1938	50	0	6,487	000		3	0	2	1	0	0	0	0
47	Washburn, *La Salle*	1940	20	0	3,334	3,334		2	1	1	0	1	0	0	1
48	Von Ormy, *Bexar*	1933	650	0	237,858	37,087		108	0	0	1	106	0	0	106
49	Yost, *Bastrop*	1928	120	0	911,568	12,827		6	0	1	1	4	0	0	4
50	Zoboroski, *Guadalupe*	1935	180	0	209,956	20,918		21	0	0	0	14	0	0	14
	GAS ONLY														
51	Adams (Medina), *Medina*	1926	0	2,000	0	0	109	58	0	0	0	0	13	0	0
52	Chittim, *Maverick*	1929	0	100[2]	51,531	10,197	1,093	19	0	0	1	0	4	0	0
53	Totals		32,130	2,275	207,560,952	7,659,634	1,291	4,039	104	163	61	3,559	82	39	3,520

[b] Footnotes to column heads explanation of symbols are given on page 256.
[1] Abandoned 1940.
[2] Gas and distillate.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.	Repressuring Operation[d]	Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
									Depth, Avg. Ft.					
	Initial		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Name	Age[e]	Character[f]	Porosity[g]	Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	y		35.0	0.3	Navarro sands	CreU	S	15–20	220	250	20	F	Trinity sand	4,535
2	y		39	y	Dale lime, serpentine	CreU	LP	Por	2,050	2,240	y	Intn	Austin chalk	2,250
3	y		37	0.8	Austin chalk, Edwards lime	CreU	L	Por	1,816	2,275	y	F	Edwards lime	2,450
4	y		36	0.2	Serpentine	CreU	P	12	1,750	2,075	y	Intn	Edwards lime	2,483
5	200		32	0.8	Edwards lime	CreL	L	Crev	2,210	2,235	15	F	Edwards lime	2,420
6	y	RP	37	0.2	Serpentine	CreU	P	20	850	900	y	Intn	Edwards lime	2,000
7	y		36	0	Serpentine	CreU	P	12	2,300	2,378	78	Intn	Edwards lime	2,919
8	100		35	0.2	Serpentine	CreU	P	15–20	1,650	1,700	50	Intn	Edwards lime	2,300
9	400		36	0.2	Serpentine	CreU	P	20	1,750	1,915	20	Intn	Edwards lime	3,226
10	y		21	0.1	Navarro sands	CreU	S	15	260	750	20	D	Edwards lime	1,725
11	y		34.5	y	Edwards lime	CreU	L	Por	6,167	6,182	y	F	Edwards lime	6,340
12	150		37	0.2	Dale lime, serpentine	CreU	LP	15	1,915	2,250	30	Intn	Edwards lime	2,661
13														
14														
15	350		36	0.8	Edwards lime	CreL	L	Por	2,650	2,700	30	F	Travis peak	5,509
16	200		33.6	0.5	Austin chalk	CreU	C	5–25	2,375	2,450	100	F	Edwards lime	3,200
17	y		36	y	Austin chalk, Buda lime	CreU	CL	Por	2,377	2,685	y	F	Edwards lime	2,830
18	400		36	0.6	Austin chalk	CreU	C	Crev	2,375	2,300	15	F	Edwards lime	2,420
19	y		21	y	Serpentine	CreU	P	y	542	714	y	Intn	Austin chalk	851
20	y		34	0.3	Navarro sands	CreU	S	16	620	790	10	F	Edwards lime	1,590
21	y		40–42	y	Navarro sands	CreU	SH	Por	700	800	y	T	Navarro	800
22	y		22	0.4	Navarro sands	CreU	S	15–20	230	760	15	A	Travis peak	3,460
23	1,240	PM	37	0.2	Serpentine	CreU	P	12	2,450	2,575	50	Intn	Edwards lime	3,250
24	y		y	y	Navarro sands	CreU	SH	Por	600	x	x	T	Edwards lime	2,008
25	y		36.5	y	Serpentine	CreU	P	Por	660	670	y	Intn	Edwards lime	1,280
26	y		31	y	Anacacho lime	CreU	L	Por	1,150	1,190	y	N	Austin chalk	1,227
27	y		23	0.6	Edwards lime	CreL	L	30	1,285	1,315	35	F	Travis peak	3,360
28	y		33.4	y	Navarro-Taylor	CreU	S	Por	1,480	1,620	18	F	Edwards lime	2,250
29	1,250		31.5	0.4	Serpentine	CreU	P	12	1,535	1,820	x	Intn	Edwards lime	2,050
30	1,500		27	0.9	Edwards lime	CreL	L	25	2,100	2,200	50	F	Schist	7,859
31	y		34	0.4	Serpentine	CreU	P	15–25	720	757	x	Intn	Taylor marl	850
32	1,250		37	0.9	Austin chalk	CreU	C	35	2,260	2,310	30	F	Edwards lime	2,800
33	y		38	0.2	Navarro sands	CreU	SH	Por	600	1,700	15	T	Edwards lime	5,000
34	340		27	0.8	Taylor marl	CreU	SL	Por	2,570	2,585	30	F	Edwards lime	3,342
35	1,500		28	0.4	Navarro sands, Austin chalk	CreU	SC	Por	3,920	5,850	15 x	N	Travis peak	10,050
36	y		23	y	Austin chalk	CreU	C	Por	1,100	y	y	F	y	y
37	y		37	y	Dale lime	CreU	L	Por	y	2,300	y	F	Edwards lime	2,550
38	y		39	y	Austin chalk, serpentine	CreU	CP	Por	1,667	1,747	y	F	Austin chalk	1,777
39	200		36	0.6	Edwards lime	CreL	L	30	2,670	2,740	25	F	Edwards lime	2,918
40	300		36	1.4	Navarro and Taylor sands	CreU	SH	22	1,200	2,100	30	TF	Travis peak	5,311
41	y		32	0.5	Navarro sands	CreU	S	16	600	800	10	F	Glen Rose	3,850
42	y		38.3	y	Buda lime	CreL	L	Por	2,012	2,298	y	F	Edwards lime	2,382
43	y		18–19	0.4–0.7	Navarro sands	CreU	SH	15–20	290 940	400 960	15 10	F T	Edwards lime	2,048
44	y		38	y	Austin chalk, Buda lime	CreU & L	CL	Por	2,340	2,703	60	F	Buda lime	2,703
45	400		37	0.3	Serpentine	CreU	P	25	700	1,000	75	Intn	Travis peak	3,290
46	y		36	y	Serpentine	CreU	P	Por	1,230	1,336	100	Intn	Austin chalk	1,900
47	y		41	y	Wilcox sands	Eoc	S	Por	4,860	4,867	7	y	Navarro	8,300
48	y		34	0.4	Navarro sands	CreU	SH	10	506	730	20	F	Edwards lime	2,835
49	400		27	0.3	Serpentine	CreU	P	15–25	1,335	1,500	100	Intn	Edwards lime	2,600
50	150		30.4	0.8	Austin chalk	CreU	C	10	2,050	2,200	75	F	Edwards lime	2,600
51	y				Navarro and Taylor sands	CreU	SH	Por	900	y	y	F	Edwards lime	2,289
52	y		42–44	y	Buda, Edwards, Glen Rose	CreL	L		3,205 3,255 5,650	y y y	y	A	Travis peak	7,635
53														

Tenney Creek, Caldwell County.—Weigand Brothers No. 1 Hill, discovery well of the Tenney Creek field, was completed on Aug. 9, 1940, from Austin chalk and Buda lime 2340 to 2703 ft., flowing 216 bbl. per day, 220-lb. tubing, 700-lb. casing pressures, 38° gravity. Credit for discovery of this field is due to both surface and subsurface geology in an area along trend to the northeast of the Salt Flats fault system. At the end of the year, two producing oil wells had been completed and the field had produced 4188 barrels.

Day Field, Guadalupe County.—A. J. Hollifield (Dees and Freeland) No. 1 Day, discovery well of the Day field, in the extreme eastern corner of Guadalupe County, was completed on Feb. 27, 1940, from a fault crevice in the Austin chalk and Buda lime from 2337 to 2685 ft., pumping 35 bbl. per day, 37.6° A.P.I. gravity. Subsurface geology from wells drilled in the area indicated considerable faulting along a southwest trend from the Salt Flats fault system. Only one well had been successfully completed at the end of the year, with a total production of 575 barrels.

Washburn Field, La Salle County.—H. R. Cullen (Quintana Petroleum Co.) No. 1 Washburn, discovery well of the Washburn field, in the east central part of La Salle County, was completed on Sept. 17, 1940, from sand in the lower Wilcox (Eocene) formation from 4860 to 4867 ft., flowing 114 bbl. per day, ⅜-in. choke, 50-lb. tubing, 600-lb. casing pressures, 41° A.P.I. gravity. Structural conditions indicating an anticline or nose were determined from surface, core-drilling, radio beam and seismograph methods. Of considerable importance to further development along this trend for lower Wilcox production are the shows of gas and oil which this well had in sands from 4752 to 4785 ft., 5060 to 5080 ft. and 5413 to 5430 ft. At the end of the year, only one well had been successfully completed, which produced a total of 3334 barrels.

ACKNOWLEDGMENT

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Oil and Gas Development in South Texas during 1940

By Michel T. Halbouty,* Member A.I.M.E.

The area for which oil and gas developments in South Texas are reported for 1940 in this paper covers the same counties that were included in the reports for 1938 and 1939, with the addition of LaSalle County. LaSalle County is included in the Laredo district of South Texas, which totals seven counties for that district. The Corpus Christi district remains the same, with nine counties. The two districts together comprise what is known as the South Texas area for this report.

Continued exploration along established trends and beyond proven field limits during 1940 provided South Texas with new fields and new producing levels at a rate of discovery fairly comparable with the high records set during recent years. The wells drilled in the counties within this district (including LaSalle) numbered 1656, approximately 8 per cent below the 1801 figure of last year. However, *rank* wildcats totaled 336, an increase of 17.5 per cent compared to the 286 drilled in 1939. Therefore, since new field discoveries numbered 25 in 1940 against 29 in 1939, the rate of new field discoveries in 1940, based upon rank wildcats drilled, was 1/13.4 while that of 1939 was 1/9.86, which shows a decrease of about 25 per cent in the rate of new fields. The rank wildcat tests in 1940 gave the following results: 18 produced oil, 4 produced distillate with gas, 3 produced only gas, and 311 were dry holes (Table 5). Of the 1320 tests drilled in already proven fields or as extensions to proven areas (representing a decline of 12.8 per cent from last year's total of 1515 tests), 1048 produced oil or distillate, 60 produced gas and 212 were dry holes (Table 4). Of the producers, 50 found new sands or crude-in-distillate-sands in existing fields.

Among the several fields subjected to extensive development were: Colorado, Jim Hogg County; East White Point, San Patricio and Nueces County; Rincon and Sun, Starr County; Glen, Webb and Zapata Counties; Wade City and Orange Grove, Jim Wells County; Stratton and South Clara Driscoll, Nueces County, and Aransas Pass, San Patricio and Aransas Counties.

The development of important crude reserves on structures formerly considered primarily distillate fields has probably been the most important phase of the year's operations in South Texas. The Rincon, Stratton, Agua Dulce, Wade City, Odem and Robston fields provided the new crude sand discoveries. At some places crude production was opened by exploratory wells that found new sand horizons; in others by flank wells that found already discovered distillate sands sufficiently low to provide crude production. Rincon, Starr County, with its multiple sands, is now believed to be one of South Texas' largest crude-oil reserves.

Offshore drilling showed important results during the year, including the discovery of two new submerged fields and the extension of the East White Point field into offshore Nueces County. The new marine fields are: East Flour Bluff,

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TABLE I.—*Oil and Gas Production in South Texas*

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Number of Oil and/or Gas Wells					Oil-production Methods, End of 1940	
								During 1940	End of 1940			Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	Completed to End of 1940	Completed	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift
1	Adami, *Webb*	1939	400	10	245,994	233,142	72	53	4	67	0	0	67
2	Agua Dulce,[1] *Nueces*	1928	300	9,750[2]	847,562	127,946	114	18	19	5	74[2]	4	1
3	East Agua Dulce, *Nueces*	1940	0	20[3]	500	500	1	1	0	0	1[3]		
4	Albercas, *Webb*	1927	250	200	2,516,082	16,011	100	0	7	16	0	0	16
5	Alfred,[4] *Jim Wells*	1938	400	0	200,970	113,217	20	13	1	19	0	17	
6	Alice, *Jim Wells*	1938	1,280	400[3]	2,016,975	617,657	74	0	15	55	2[3]	52	
7	East Alice (Tom Graham), *Jim Wells*	1938	750	360[3]	805,694	475,311	46	3	7	36	2[3]	34	
8	Alta Mesa, *Brooks*	1926	420		743,616	259,557	30	0	2	21	1	1	20
9	Alta Verde, *Brooks*	1936	100	60	30,617	541	6	0	2	0	0	0	0
10	Alworth,[5] *Jim Hogg*	1926	80	570	27,793	0	16	0	0	0	0	0	0
11	Andrews, *Zapata*	1924	0	2,000	Gas	0	12	0	12	0	0	0	0
12	Angelita, *San Patricio*	1934	60	0	36,798	742	3	0	2	0	0	0	0
13	Aransas (gas), *San Patricio*	1931	0	760	Gas	Gas	19	0	17*y*	0	2		
14	Aransas Pass (McCampbell), *San Patricio and Aransas*	1936	3,200	450[3]	8,663,956	3,047,988	358	66	43	275	22[3]	225	50
15	*Armagosa, Jim Wells*	1931	0	400	Gas	Gas	6	0	1	0	5		
16	Arroyo Grande, *Starr*	1924	0	320	Gas	Gas	8	1	1	0	0		
17	Aviator, *Webb*	1922	955	320	5,982,120	100,634	216	0	12	73	0	0	73
18	Baffins Bay, *Kleburg*	1940	20	0	5,610	5,610	1	1	0	1	0	1	0
19	Baldwin (South Saxet), *Neuces*	1935	270	40	761,501	81,723	9	0	0	8	1	0	8
20	Bandera, *Jim Wells*	1938	0	40[3]	1,987	488	1	0	1	0	0		
21	Barbacoas, *Starr*	1933	80	580	35,073	1,699	14	1	1	2	0	1	1
22	Benavides (North Sweden), *Duval*	1937	3,900	600[2]	9,057,610	1,901,715	275	1	21	246	8	171	75

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Includes North Agua Dulce.
[2] Gas, or distillate and gas.
[3] Distillate and gas.
[4] Includes West Alfred.
[5] Depleted.

TABLE I.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In. Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1			20.8	Mirando	Eoc	S	Por	975	1,000	7	ML	Yegua	1,517
			Gas	Catahoula	Olig	S		1,998	2,400	10			
	800		55	Frio	Olig	S		4,650	4,675	9			
	1,650		35.4–59	Frio	Olig	S		4,800	4,900	15			
	1,750		56	Frio	Olig	S	(Avg.)	5,081	5,088	7			
2	1,800	PM	37.5–59.7	Frio	Olig	S	30	5,295	5,307	10	DF	Yegua	13,728
	2,000		42.6–56	Frio	Olig	S		5,575	5,700	15			
	2,500		55–60	Frio	Olig	S		6,615	6,740	15			
	1,750		39.8–50.9	Frio	Olig	S		6,800	6,938	15			
3	2,450		56	Frio	Olig	S	Por	7,200	7,220	20	DF	Vicksburg	7,503
4	600		20.4	Cole	Eoc	S	Por	2,125	2,175	17	MF	Yegua	3,710
5	125		44.7	Frio	Olig	S	30–35	3,222	3,234	11	MF	Jackson	5,774
	835		41.5	Vicksburg	Olig	S		4,660	4,695	15			
	1,350		42	Frio	Olig	S	28.7	3,480	3,600	16			
	750		38.9	Frio	Olig	S	Por	4,788	4,801	11			
6	1,900	PM	40	Frio	Olig	S	Por	5,030	5,161	12	A	Cockfield	7,335
			44.8	Frio	Olig	S	Por	5,211	5,223	12			
	900		44–60	Vicksburg	Olig	S	Por	5,350	5,375	20			
	1,200		43.6	Vicksburg	Olig	S	Por	5,450	5,576	20			
	1,350		38	Frio	Olig	S	Por	3,480	3,496	15			
7	800	PM	54	Frio	Olig	S	Por	4,675	4,700	10	A	Vicksburg	5,760
	1,500		56	Frio	Olig	S	Por	5,125	5,175	12			
	1,200		42.6–56	Vicksburg	Olig	S	Por	5,300	5,400	18			
	500		Gas	Oakville	Mio	S	Por	1,100	1,140	20			
8	500		24.5	Catahoula	Olig	S	Por	2,450	2,485	12	D	Jackson	8,022
	175		24	Catahoula	Olig	S	Por	3,000	3,025	10			
	575		25.5	Catahoula	Olig	S	Por	3,550	3,585	20			
9	100		21.5	Caprock	Mio	S	Por	916	926	10	DS	Yegua	5,096
10			21	Upper Jackson	Eoc	S	Por	1,020	1,030	6	ML	Jackson	2,199
11			Gas	McElroy	Eoc	S	Por	1,510	1,515	5	MF	Yegua	2,312
12	1,550		38	Frio	Olig	S	Por	5,370	5,382	10	NF	Frio	7,131
	Pump		36	Frio	Olig	S	Por	6,225	6,235	10			
13	1,480		Gas	Catahoula	Olig	S	Por	3,653	3,663	10	D	Frio	6,026
	2,250		49.3	Marginulina	Olig	S		6,539	6,554	15			
	2,200		42.4	Frio	Olig	S		6,780	6,888	15			
14	2,700		38.8	Frio	Olig	S	25–34	7,080	7,180	18	AF	Frio	9,492
	2,500		41.2	Frio	Olig	S		7,200	7,270	15			
	2,300		58	Frio	Olig	S		7,345	7,419	15			
	2,600		56	Frio	Olig	S		7,454	7,461	7			
15			Gas	Discorbis-Het.	Olig	S	Por	2,170	2,200	10	D	Yegua	6,315
				Jackson	Eoc	S	Por	435	450	8			
16			Gas	Cook Mt.	Eoc	S	Por	2,120	2,161	12	MF	Carrizo	4,015
				Mt. Selman	Eoc	S	Por	3,208	3,214	6			
17			21	Mirando	Eoc	S	Por	1,525	1,660	11	MF	Cook Mt.	3,975
18	1,225		39.3	Frio	Olig	S	Por	7,394	7,450	10	A	Frio	9,428
			Gas	Oakville	Mio	S	Por	3,230	3,250	12			
19	225		25.9	Catahoula	Olig	S	Por	3,874	3,880	6	AF	Frio	6,610
			23.3	Catahoula	Olig	S	Por	4,050	4,074	12			
20	3,550		Gas, Dist.	Jackson	Eoc	S	Por	6,408	6,416	8	AF	Yegua	8,302
			Gas	Catahoula	Olig	S	Por	685	715	10			
21			24.9–Gas	Frio	Olig	S	Por	2,450	2,950	15	DF	Yegua	6,567
	2,200		58	Cockfield	Eoc	S	Por	5,376	5,398	22			
	1,600		41.8	Cole	Eoc	S	Por	3,840	3,975	22			
	925		42.9–47.2	Chernosky	Eoc	S	Por	4,357	4,552	15			
22	460		43.3	Upper Govt. Wells	Eoc	S	Por	4,730	4,755	20	AF	Yegua	6,510
	750		44.2	Lower Govt. Wells	Eoc	S	Por	4,755	4,830	25			
	400		39.6–60	Pettus	Eoc	S	Por	5,310	5,382	22			
	190		45	Cockfield	Eoc	S	Por	5,486	5,518	17			

NOTE: S = Soft sand.

TABLE I.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift
23	Ben Bolt, *Jim Wells*	1939	1,900	40	837,354	739,252	52	28	2	50	0	50	0
24	Bird Island, *Kleburg*	1938	40	80	23,823	15,457	3	1	2	1	0	1	0
25	Blas Uribe, *Zapata*	1934	0	80	Gas		3	0	1	0	0		
26	Blucher, *Jim Wells*	1939	0	40[3]	3,461	1,220	1	0	1	0	0		
27	Boyle, *Starr*	1940	160	0	24,699	24,699	8	8	0	8	0	8	0
28	Bridwell, *Duval*	1940	100	20	12,394	12,394	5	5	0	5	0	5	0
29	Calliham,[6] *McMullen*	1918	500	730	880,857	59,431	141	4	12	61	0	0	61
30	Camada, *Jim Wells*	1939	40	0	3,815	1,525	2	0	1	1	0	1	0
31	Campana, *McMullen*	1938	10	0	*y*	350	1	0	0	1	0	0	1
32	Captain Lucey, *Jim Wells*	1932	120	520	483,524	36,104	22	0	4	5	12	4	1
33	Carolina-Texas, *Webb*	1921	110	1,460[2]	264,752	3,805	66	1	10	1	9	0	1
34	Casa Blanca,[8] *Duval*	1938	400	100	344,551	110,380	47	9	8	37	2	2	35
35	Casa Blanca, North, *Duval*	1939	100	0	59,789	32,944	9	0	0	9	0	1	8
36	Cedro Hill, *Duval*	1938	660	60	243,690	192,895	73	51	12	60	1	21	39
37	Chapman Ranch, *Nueces*	1937	50	40[3]	43,782	1,000*y*	2	0	1	0	1[3]	0	0
38	Charamousca,[10] *Duval*	1935	250	0	459,830	136,053	23	1	4	16	0	0	16
39	Charco Redondo, *Zapata*	1913	570	60	190,058	4,894	328	0	15	46	0	0	46
40	Chiltipin, *Duval*	1939	60	20	14,109	9,488	4	1	3	1	0	1	0
41	Clara Driscoll,[11] *Nueces*	1935	2,200	300[2]	3,087,696	981,029	137	35	15	114	6[2]	87	27
42	Clark-Muil, *Jim Wells*	1939	100	80	41,170	23,127	8	1	4	3	1	3	0
43	Clopton-Green, *Starr*	1937	0	10	Gas	0	1	0	0	0	0		
	Cole Group, *Duval, Webb*												
44	Gas	1924	0	7,000	Gas	Gas	107	2	23	0	64		
45	O'Hern	1927	2,300	2,200	9,797,331	1,324,966	274	1	15	223	18	0	223
46	Cole West	1927	500	1,000	4,430,096	212,159	126	7	10	69	5	0	69
47	Bruni[12]	1934	880	160	2,767,866	90,819	62	2	18	24	2	1	23
48	Colmena, *Duval*	1934	240	400	395,457	65,523	36	0	5	24	1	4	20
49	Colorado, *Jim Hogg*	1936	1,100	20	984,183	784,741	117	98	6	111	0	102	9
50	Comitas (Haynes), *Zapata*	1934	750	40	1,529,128	229,770	196	5	20	146	0	0	146

[6] Includes South Calliham.
[8] Includes West Casa Blanca.
[10] Includes S.R.C.
[11] Includes South Clara Driscoll.
[12] Includes East Brun.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In., Initial	Repressuring Operation[d]	Character of Oil, Gravity A.P.I. at 60°F., Weighted Average	Producing Formation, Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft., Top Prod. Zone	Depth, Avg. Ft., Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940, Name	Depth of Hole, Ft.
23			30	Frio	Olig	S	Por	4,863	4,875	12	A	Jackson	6,140
	625		46	Frio	Olig	S	Por	4,906	4,920	15			
	875		42	Frio	Olig	S	32.7	5,181	5,317	15			
	2,100		42.5	Vicksburg	Olig	S	Por	5,370	5,501	15			
24	2,700		44	Frio	Olig	S	Por	7,200	7,310	80	AF	Frio	9,636
25			Gas	Jackson	Eoc	S	Por	1,825	1,840	15	ML	Yegua	3,000
26	3,600		54	Vicksburg	Olig	S	Por	7,500	7,560	20	A	Vicksburg	8,004
27	590		47.7	Frio	Olig	S	Por	3,159	3,186	15	A(y)	Jackson	4,503
	1,000		44	Frio	Olig	S	Por	3,475	3,503	12			
28	1,175		43.5	Pettus	Eoc	S	Por	4,292	4,327	10	MF(y)	Yegua	4,657
29			20	Cole-Hock.[7]	Eoc	S	Por	780	876	28	MF	Carrizo	5,301
			20.6	Govt. Wells-Pettus[7]	Eoc	S	Por	1,030	1,060	10			
			Gas	Loma Novia	Eoc	S	Por	1,230	1,236	6			
30	850		44.3	Hockleyensis	Eoc	S	Por	5,627	5,637	10	ML	Yegua	7,041
31	140		24	Govt. Wells	Eoc	S	Por	2,492	2,517	20	MF	Pettus	3,102
32	1,100		Gas	Frio	Olig	S	Por	3,893	4,000	6	AF	Jackson	6,500
	200		36.4	Frio	Olig	S	Por	5,350	5,370	20			
	725		41.4	Vicksburg	Olig	S	Por	5,679	5,685	7			
33			Gas	Cole	Eoc	S	Por	1,270	1,280	10	DF	Mt. Selman	5,474
			Gas	McElroy	Eoc	S	Por	1,800	2,200	65			
			34	Cockfield	Eoc	S	Por	2,597	2,615	10			
			27.6	Yegua	Eoc	S	Por	2,947	3,198	50			
	1,625		42–60	Queen City	Eoc	S	Por	4,996	5,056	60			
34			19.7	Cole[9]	Eoc	S	Por	994	1,006	10	ML	Jackson	2,212
			19.7	Cole	Eoc	S	Por	1,180	1,190	10			
35			20.8	Cole	Eoc	S	Por	1,030	1,059	9	ML	Jackson	1,788
36			19.2	Cole	Eoc	S	Por	1,436	1,480	10	ML	Jackson	2,530
37	550		40.8	Catahoula	Olig	S	Por	5,046	5,058	12	ML	Frio	7,012
	625		41.8	Frio	Olig	S	Por	6,464	6,484	20			
38			20	Upper Hockleyensis	Eoc	S	Por	1,094	1,101	7	MF	Cook Mt.	3,892
	75		19.8	McElroy	Eoc	S	Por	1,525	1,581	10			
39			17	Frio	Olig	S	Por	150	200	8	ML	Yegua	3,010
			Gas	Jackson	Eoc	S	Por	989	995	5			
40	1,440		49.6	Pettus	Eoc	S	Por	4,760	4,795	10	MF	Yegua	5,054
41	450		23.5	Heterostegina	Olig	S	Por	3,787	3,980	12	DF	Vicksburg	8,194
			31.5	Frio	Olig	S	Por	4,642	4,748	10			
			37.3	Frio	Olig	S	Por	4,986	5,133	15			
	2,150		34.2–36.6	Frio	Olig	S	Por	5,255	5,477	14			
	375		40.7–58	Frio	Olig	S	Por	5,502	5,830	15			
	200		38.5	Frio	Olig	S	Por	6,487	6,660	10			
42	1,400		60	Frio	Olig	S	Por	4,795	4,835	20	N	Vicksburg	5,850
	900		40.2	Vicksburg	Olig	S	Por	5,326	5,330	4			
	1,750		58	Vicksburg	Olig	S	Por	5,557	5,572	12			
43	425		Gas	Cole	Eoc	S	Por	1,604	1,614	10	ML	Cook Mt.	4,620
											A	Wilcox	10,295
44			Gas	Frio	Olig	S	Por	500	515	10	A	Reklaw	6,394
			Gas	Cole	Eoc	S	Por	1,650	1,811	10			
45			Gas	Mirando	Eoc	S	Por	2,314	2,450	10	A	Queen City	5,057
			29.4	Caddell-Cockfield	Eoc	S	Por	2,750	2,945	15			
46			21.5	Mirando	Eoc	S	Por	2,300	2,350	11	A	Queen City	5,225
			Gas	Cockfield	Eoc	S	Por	2,900	2,925	10			
47	900		39.9	Yegua	Eoc	S	Por	3,250	3,280	10	A	Wilcox	10,295
			38.5–42.4	Yegua	Eoc	S	Por	3,400	3,450	14			
	450		44	Cook Mt.	Eoc	S	Por	3,938	3,973	15			
	450		46	Queen City	Eoc	S	Por	5,620	5,675	15			
48	525		18.9	Cole	Eoc	S	Por	1,486	1,553	19	ML	Yegua	3,396
49			47.2	Cockfield	Eoc	S	Por	3,000	3,050	10	ML	Yegua	3,202
50			20.6	McElroy	Eoc	S	Por	800	1,000	10	ML	Cook Mt.	3,502

[7] In Calliham.
[9] In West Casa Blanca.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift
51	Conoco Driscoll, *Duval*	1924	1,020	980	2,945,595	856,443	80	16	5	54	3	46	8
52	Corpus Christi (Saxet Heights) *Neuces*	1935	1,500	200	6,744,059	223,834	252	1	90*y*	33	3	23	10
53	Crowther,[5] *McMullen*	1915	80	0	25,000	0	23	0	0	0	0	0	0
54	Cuellar, *Zapata*	1927	340	220	2,593,701	28,508	86	0	6	24	2	0	24
55	Eagle Hill, *Duval*	1933	550	200	1,215,762	198,247	61	0	3	50	4	3	47
56	Edinburg, *Hidalgo*	1935	20	0	500	0	1	0	0	0	0	0	0
57	El Mesquite, *Duval*	1935	10	0	976	0	1	0	0	0	0	0	0
58	El Tanque (South Ricaby), *Starr*	1937	280	30	360,211	79,451	22	2	4	16	0	2	14
59	Escobas-Jennings, *Zapata*	1914	3,700	2,000	9,183,733	811,846	535	16	15	393	4	0	393
60	Ezzell, *McMullen, Live Oak*	1937	1,450	100	2,158,000	438,130	149	1	4	143	0	0	143
61	Fitzsimmons, *Duval*	1938	790	0	1,762,627	734,246	79	2	1	78	0	75	3
62	Fitzsimmons, East, *Duval*	1940	10	0	600	600	1	1	0	1	0	0	1
63	Flour Bluff, *Nueces*	1936	2,280	320[2]	5,882,104	1,107,807	116	0	8	107	1	91	16
64	Flour Bluff, East, *Nueces*	1940	400	0	500	500	10	10	0	10	0	10	0
65	Gallagher, *Jim Wells*	1940	60	0	26,173	26,173	3	3	0	3	0	3	0
66	Glen, *Webb, Zapata*	1940	450	30	109,276	109,276	48	48	3	45	0	16	29
67	Government Wells, *Duval*	1928	7,500	600	45,174,799	3,495,287	830	1	60	666	5	16	650
68	Guerra (Cuevitas), *Starr*	1933	400	400	1,112,672	158,689	21	0	6	13	0	9	4
69	Hayden, *Starr*	1937	0	40	Gas	Gas	2	1	1	0	0		
70	Henne-Winch-Farris, *Jim Hogg*	1924	720	440	3,212,257	1,230	181	0	0	1	0	0	1
71	Henshaw, *Jim Wells*	1940	20	20	5,182	5,182	2	2	1	1	0	1	0
72	Hoffman, *Duval*	1933	3,300	500	5,352,424	1,885,420	365	35	23	327	5	10	317
73	Holbein, *Jim Hogg*	1940	10	0	2,591	2,591	1	1	0	1	0	1	0
74	Holland-Hebbronville (Gutierrez), *Jim Hogg*	1939	10	10[3]	2,199	1,884	2	1	0	1	1[3]	0	1
75	Jacob,[13] *McMullen*	1926	1,230	80	1,487,080	118,699	127	0	4	80	0	0	80
76	Kelsey, *Jim Hogg, Brooks, Starr*	1938	1,540	160[2]	951,461	635,190	85	33	5	79	1	79	0
77	Killam, *Webb*	1937	650	150	809,595	121,833	92	0	25*y*	51	0	0	51
78	North Killam,[14] *Webb*	1938	80	20	36,974	4,813	7	0	1	6	0	0	6
79	Kingsville, *Kleburg*	1920	240	675	731,752	15,240	20	0	1	9	1	1	8
80	Kohler,[15] *Duval*	1926	360	5,000	640,494	24,015	91	0	30*y*	11	12	3	8

[13] Includes North Jacob.
[14] Includes Houser.
[15] Includes North (Deep) Kohler.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft
			22.5	Cole	Eoc	S	Por	2,448	2,535	20			
51			23.4	Hockleyensis	Eoc	S	Por	2,884	2,904	10	A	Yegua	4,695
			36.4	Govt. Wells	Eoc	S	Por	3,250	3,561	15			
52	1,650		25	Catahoula	Olig	S	Por	3,974	4,100	8	A	Frio	7,531
	825		36.5	Heterostegina	Olig	S	Por	5,157	5,167	10			
53			18	Diboll	Eoc	S	Por	500	520	10	ML	*x*	*x*
54	385		Gas	McElroy	Eoc	S	Por	1,100	1,116	16	ML	Mt. Selman	4,532
			20.9	McElroy	Eoc	S	Por	1,325	1,350	10			
55			19	Cole	Eoc	S	Por	1,450	1,540	20	MF	Cockfield	2,752
			23	Govt. Wells	Eoc	S	Por	2,120	2,150	20			
56			*y*	Frio	Olig	S	Por	6,685	6,770	20	D	Frio	7,508
57			43	Cockfield	Eoc	S	Por	2,850	2,862	12	ML	Yegua	3,502
			Gas	Catahoula	Olig	S	Por	425	429	4			
58	200		31	Frio	Olig	S	Por	1,739	1,775	14	ML	Frio	2,379
			30	Frio	Olig	S	Por	1,866	1,879	6			
			20.9	Jackson	Eoc	S	Por	900	1,050	10			
59			20.9	Jackson	Eoc	S	Por	1,137	1,350	15	AF	Reklaw	4,645
			20.9	Jackson	Eoc	S	Por	1,450	1,600	10			
60	90		20	Loma Novia	Eoc	S	Por	1,490	1,550	11	ML	Cook Mt.	3,108
61	1,200		46	Hockleyensis	Eoc	S	Por	3,592	3,623	15	MF	Yegua	5,285
	370		47	Pettus	Eoc	S	Por	4,260	4,303	25			
62			43.7	Yegua	Eoc	S	Por	4,900	4,916	10	MF	Yegua	5,087
63	1,420		41.5–43.8	Marginulina	Olig	S	Por	6,590	6,696	20	AF	Frio	7,504
64	1,725		41.6	Marginulina	Olig	S	Por	6,780	6,800	20	AF	Frio	8,395
65	600		39	Frio	Olig	S	Por	5,189	5,215	18	NF	Jackson	6,260
	1,330		39	Vicksburg	Olig	S	Por	5,744	5,761	15			
66			22.1	Mirando	Eoc	S	Por	2,160	2,185	12	NL	Yegua	2,861
			Gas	Cole	Eoc	S	Por	1,550	1,575	17			
67	600		21.6–23	Govt. Wells	Eoc	S	Por	2,200	2,380	19	MF	Mt. Selman	5,858
			26	Loma Novia	Eoc	S	Por	2,400	2,450	11			
	660		26	Yegua	Eoc	S	Por	2,982	2,985	3			
			34.5	Cole *y*	Eoc	S	Por	1,745	1,785	10			
68	400		32	Upper Govt. Wells *y*	Eoc	S	Por	2,047	2,055	8	MF	Yegua	3,600
			35.2	Lower Govt. Wells *y*	Eoc	S	Por	2,209	2,232	23			
69	550		Gas	Frio	Olig	S	Por	1,305	1,318	13	ML	Jackson	2,644
				Jackson	Eoc	S	Por	2,619	2,644	25			
70			20.2	Mirando	Eoc	S	Por	1,944	2,100	16	MF	Yegua	3,546
71	520		31.1	Frio-Vicksburg	Olig	S	Por	5,133	5,144	10	N	Jackson	5,885
	890		25.5	Hockleyensis (Argo)	Eoc	S	Por	2,550	2,688	20			
72	475		23	Govt. Wells	Eoc	S	Por	2,720	2,800	15	ML	Yegua	3,800
	200		21.5	Loma Novia	Eoc	S	Por	2,820	2,895	25			
73			24.5	Pettus	Eoc	S	Por	2,795	2,811	15	NL	Yegua	3,150
74	Pump		32.6	Loma Novia	Eoc	S	Por	3,217	3,223	6	ML	Yegua	3,731
	1,200		55	Cockfield	Eoc	S	Por	3,618	3,656	15			
			Gas	Mirando	Eoc	S	Por	780	790	8			
75			21.5	Pettus	Eoc	S	Por	920	975	7	ML	Mt. Selman	3,171
			20.5	Cockfield	Eoc	S	Por	1,050	1,070	8			
	1,170		44.7	Frio	Olig	S	Por	4,671	4,754	15			
76	1,050		42	Govt. Wells	Eoc	S	Por	6,099	6,107	8	A	Yegua	7,507
	950		55	Lower Jackson	Eoc	S	Por	6,420	6,440	15			
77	225		21–22	Mirando	Eoc	S	Por	1,920	2,035	12	ML	Yegua	3,011
			Gas & 45	Cockfield	Eoc	S	Por	2,475	2,500	15			
78			22	Mirando	Eoc	S	Por	2,046	2,096	7	ML	Yegua	3,060
	800		Gas & 45	Cockfield	Eoc	S	Por	2,492	2,524	23			
79			21.5	Miocene	Mio	S	Por	1,400	2,900	20	D	Frio	6,922
			22	Oligocene	Olig	S	Por	3,217	3,238	20			
			21.5	Cole	Eoc	S	Por	1,748	1,850	12			
80			21.5	Govt. Wells	Eoc	S	Por	2,438	2,500	12	ML	Carrizo	7,723
	320		22.5	Mirando	Eoc	S	Por	2,613	2,800	29			

TABLE I.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Number of Oil and/or Gas Wells					Oil-production Methods, End of 1940	
								During 1940	End of 1940			Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	Completed to End of 1940	Completed	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift
81	Kreis, *Duval*	1940	10	0	300	300	1	1		1	0	0	1
82	Labbe, *Duval*	1934	200	500	301,274	66,375	29	0	8	13	5	4	9
83	LaBlanca, *Hidalgo*	1936	0	1,000[3]	512,394	128,077	10	0	3	0	7[3]		
84	La Gloria, *Jim Wells*	1939	40	200[3]	22,310	13,991	4	0	2	1	1[3]	0	1
85	La Reforma, *Starr*	1938	0	100[3]	10,335	594	2	0	2	0	0		
86	La Reforma, South *Starr*	1939	0	50[3]	Distillate	0	1	0	1	0	0		
87	Las Animas, *Jim Hogg*	1937	50	80	36,612	9,485	8	0	6	2	0	2	0
88	Las Vieja,[5] *Willacy*	1936	40	0	17,954	0	1	0	0	0	0	0	0
89	Laurel, *Webb*	1932	220	320	686,976	4,551	33	0	3	4	2	0	4
90	Leaseholders,[16] *Webb*	1922	10	20	25,000	0	3	0	0	0	0	0	0
91	Loma Alta, *McMullen*	1935	20	0	130,514	13,484	4	0	0	3	0	0	3
92	Loma Novia, *Duval*	1934	7,410	270	22,954,557	2,795,457	758	0	65y	610	2	0	610
93	Loma Valdez, *Webb*	1938	0	10	Gas	0	1	0	1	0	0		
94	Loma Vista, *Duval*	1936	10	10	19,753	2,143	2	0	0	1	0	0	1
95	London, *Nueces*	1937	80	40[3]	69,737	11,743	4	0	1	2	0	1	1
96	Longhorn, *Duval*	1938	960	0	1,113,341	678,057	48	7	2	46	0	38	8
97	Lopena, *Zapata*	1934	0	1,100	Gas	Gas	14	1	0	0	14		
98	Lopez, *Webb-Duval*	1935	3,450	240	10,060,415	1,645,584	369	0	10	339	3	93	246
99	Los Olmos, *Starr*	1925	240	310	615,056	25,559	108	1	1	73	0	0	73
100	Los Picachos	1938	20	0	576	0	1	0	1	0	0	0	0
101	Luby, *Nueces*	1937	3,000	40	5,438,720	1,428,789	149	1	3	146	0	146	0
102	Luby, East, *Nueces*	1940	0	40[3]	150	150	1	1	0	0	1[3]		
103	Luby, North, *Nueces*	1939	60	0	36,066	26,187	3	1	0	3	0	2	1
104	Lundell, *Duval*	1937	780	120	648,348	263,287	90	26	2	85	3	35	50
105	Magnolia City, *Jim Wells*	1939	120	80[2]	109,350	92,328	9	7	0	6	3[2]	6	0
106	Manila, *Jim Hogg*	1940	130	10	43,168	43,168	13	13	0	13	0	13	0
107	Martinez, *Zapata*	1929	0	850	Gas	Gas	27	0	7	0	18		
108	Mathis, *San Patricio*	1924	0	100	Gas	0	6	0	0	0	0		
109	East Mathis, *San Patricio*	1939	60	40[3]	7,474	6,724	3	1	2	1	0	1	0
110	McAllen (Pharr), *Hidalgo*	1938	0	240[3]	10,831	5,093	2	0	1	0	1[3]		
111	McBride, *Webb*	1940	0	10	Gas	Gas	1	1	1	0	0		
112	Mercedes (Capsillo), *Hidalgo*	1935	0	560[3]	162,527	5,073	7	0	1	0	6[3]		
113	Mestinas, *Hidalgo*	1935	0	40[3]	See San Salvador		1	0	0	0	1[3]		
114	Midway, *San Patricio*	1937	440	0	880,168	346,784	22	9	3	19	0	17	2
115	Minnie Bock, *Nueces*	1939	780	0	482,514	379,104	39	16	1	38	0	36	2
116	Mirando City, *Webb*	1921	1,430	500	9,105,586	108,897	295	0	14	73	1	0	73
117	Mirando Valley, *Zapata*	1921	1,000	320	1,284,560	347,806	146	28	12	93	2	6	87
118	Moca, *Webb*	1932	80	20	1,055,008	78,908	12	0	0	11	0	0	11

[16] Field abandoned.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
81			29.2	Loma Novia	Eoc	S	Por	3,249	3,258	9	ML	Loma Novia	3,261
82	890		Gas	Hockleyensis	Eoc	S	Por	2,453	2,460	7	ML	Yegua	4,054
	260		25.4	Loma Novia	Eoc	S	Por	2,800	2,900	19			
83		PM	62	Frio	Olig	S	Por	6,650	6,683	20	D	Vicksburg	8,893
	2,700		52	Frio	Olig	S	Por	7,450	7,480	25			
	3,000		48	Frio	Olig	S	Por	7,840	7,875	20			
	3,850		56	Frio	Olig	S	Por	8,035	8,075	25			
84	2,125		44	Frio	Olig	S	Por	6,070	6,100	15	A	Vicksburg	7,545
	2,000		56	Frio	Olig	S	Por	6,533	6,598	15			
	3,150		60	Frio	Olig	S	Por	6,998	7,011	13			
	300		60	Frio	Olig	S	Por	7,066	7,088	22			
			25	Vicksburg	Olig	S	Por	7,210	7,232	12			
85	2,125		51.6	Frio	Olig	S	Por	5,917	5,969	52	AF	Vicksburg	7,010
86	2,050		51.5	Frio	Olig	S	Por	5,798	5,832	34	AF	Vicksburg	6,566
87	200		18.5	Cole	Eoc	S	Por	1,782	1,828	22	A	Yegua	3,808
88	2,056		48	Frio	Olig	S	Por	7,630	7,646	16	D	Frio	10,286
89			Gas	Frio	Olig	S	Por	360	366	6	MF	Cook Mt.	3,165
			Gas	Mirando	Eoc	S	Por	1,770	1,777	6			
			49	Cockfield	Eoc	S	Por	2,244	2,275	7			
90			22	McElroy	Eoc	S	Por	1,049	1,055	6	ML	Mt. Selman	3,034
91	235		21–21.5	Chernosky	Eoc	S	Por	2,195	2,250	12	MF	Cockfield	2,766
92			23.9–26	Loma Novia	Eoc	S	Por	2,550	2,705	25	ML	Cook Mt.	4,200
	200		22	Mirando	Eoc	S	Por	2,846	2,900	15			
93	450		Gas	Cole	Eoc	S	Por	1,790	1,812	19	NL	Yegua	3,528
94			25.7	Loma Novia	Eoc	S	Por	2,914	2,922	7½	ML	Cook Mt.	4,732
95	750		24.4	Catahoula	Olig	S	Por	4,698	4,730	8	NF	Frio	7,424
	1,625		51	Catahoula	Olig	S	Por	4,752	4,906	10			
96	575		41.7	Cole	Eoc	S	Por	4,009	4,100	10	AF	Yegua	6,011
	780		45.2	Govt. Wells	Eoc	S	Por	4,885	4,914	10			
97	925		Gas	Queen City	Eoc	S	Por	2,147	2,170	23	A	Carrizo	3,502
98	760		22	Mirando	Eoc	S	Por	2,126	2,250	18	ML	Yegua	3,437
99	120		20	Frio	Olig	S	Por	250	700	17	MF	McElroy	2,612
100			24	Govt. Wells	Eoc	S	22–26	2,166	2,196	15	MF	Govt. Wells	2,196
101	1,710		45.7	Catahoula	Olig	S	Por	4,306	4,354	15	NF	Frio	7,595
			45.7	Heterostegina	Olig	S	Por	5,009	5,087	20			
			45.7	Heterostegina	Olig	S	Por	5,155	5,175	10			
102	1,320		56	Miocene	Mio	S	Por	4,023	4.038	15	NF	Frio	7,628
103	1,275		45.7	Catahoula	Olig	S	Por	4,347	4.370	14	NF	Frio	7,440
	450		45.7	Heterostegina	Olig	S	Por	5,073	5,085	12			
104	640		19.3	Cole	Eoc	S	Por	1,500	1,530	10	MF	Jackson	2,698
105	1,450		42.7	Frio	Olig	S	27.7	5,436	5,485	10	A	Jackson	6,592
	1,000		Gas	Frio	Olig	S	Por	5,561	5,569	8			
	750		40.8	Frio	Olig	S	Por	5,692	5,726	10			
106	286		24.9	Pettus	Eoc	S	Por	2,576	2,650	10	NL	Yegua	3,006
107	620		Gas	Hockleyensis	Eoc	S	Por	1,921	1,927	6	ML	Cook Mt.	3,514
108	935		Gas	Miocene	Mio	S	Por	2,375	2,414	10	MF	Jackson	5,526
109	1,450		54	Frio	Olig	S	Por	4,417	4,422	5	Nf	Jackson	6,348
	325		35.5	Frio	Olig	S	Por	5,258	5,270	12			
	1,000		41	Vicksburg	Olig	S	Por	5,600	5,627	10			
110	2,025		61.5	Frio	Olig	S	Por	5,970	5,994	24	D	Vicksburg	7,507
	1,750		58–60	Frio	Olig	S	Por	6,500	6,955	20			
	2,200		53	Vicksburg	Olig	S	Por	7,415	7,498	25			
111	650		Gas	Mirando	Eoc	S	Por	2,525	2,539	14	ML	Yegua	3,117
112	2,500		49.2–61	Frio	Olig	S	Por	7,430	7,524	16	DF	Vicksburg	9,618
	2,750		50–60	Frio-Vicksburg	Olig	S	Por	7,920	9,000[17]	15			
113	1,840		52–60	Frio	Olig	S	Por	6,658	6,748	90	D	Frio	8,123
114	1,985		28.4	Frio	Olig	S	Por	5,285	5,370	15	D	Frio	7,003
115	1,240		23.5	Catahoula	Olig	S	Por	3,787	3,900	15	Df	Frio	6,011
116			21.4	Hockleyensis	Olig	S	Por	1,530	1,540	10	ML	Reklaw	5,000
			45	Cockfield	Olig	S	Por	1,925	1,935	10			
117			20.9	Upper Hock.	Eoc	S	Por	1,415	1,425	7	ML	Cook Mt.	3,600
	35		20.9	Mirando	Eoc	S	Por	1,790	2,000	10			
118			21	Mirando	Eoc	S	Por	900	950	10	MF	Yegua	2,178

[17] Found productive on tests.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift
119	Munson, *McMullen*	1938	150	20	126,216	44,391	17	3	2	15	0	0	15
120	Muralla (Blanchard), Duval	1939	60	40[3]	25,830	17,542	3	1	0	2	1[3]	0	2
121	Nichols, *Hidalgo*	1940	10	10	1,939	1,939	1	1	0	1	0	1	0
122	Odem, *San Patricio*	1939	20	40[3]	4,113	3,513	2	1	1	1	0	1	0
123	Oilton, *Webb*	1937	700	150	1,456,782	232,181	141	1	30[y]	94	0	0	94
124	Orange Grove, *Jim Wells*	1940	520	0	191,636	191,636	19	19	0	19	0	19	0
125	Palangana, *Duval*	1928	50	0	9,846	0	5	0	0	0	0	0	0
126	Patal, *Jim Hogg*	1940	0	40	Gas	Gas	1	1	1	0	0		
127	Pena, *Duval*	1933	0	40	Gas	0	1	0	0	0	0		
128	Peters, *Duval*	1933	140	1,400	184,616	29,502	21	1	2	4	13	4	
129	Peters, East, *Duval*	1940	60	0	10,085	10,085	3	3	0	3	0	1	
130	Peyote, *Jim Hogg*	1932	0	20	Gas	0	1	0	0	0	0		
131	Piedre Lumbre, *Duval*	1935	1,000	200	1,912,507	605,120	135	2	5	123	1	12	111
132	Pietras Pintas, *Duval*	1905	150	0	154,183	31	29	0	3	0	0	0	0
133	Plymouth, *San Patricio*	1935	3,450	150[3]	20,515,286	2,739,651	190	9	8	179	3[3]	175	4
134	Plymouth, East, *San Patricio*	1938	0	120	Gas	Gas	3	1	0	0	3		
135	Premont, *Jim Wells*	1933	720	280	729,578	137,926	60	18	25[y]	30	2	16	14
136	Premont, East, *Jim Wells*	1937	280	160[3]	239,445	126,381	9	1	2	6	1[3]	6	0
137	Rancho Solo,[18] *Duval*	1935	440	160	309,271	131,247	43	6	2	38	0	0	38
138	Randado, *Jim Hogg*	1926	765	435	4,737,660	91,510	191	0	5	86	0	0	86
139	Reiser,[5] *Webb*	1909	20	1,270	4,000	0	18	0	0	0	0	0	0
140	Reynolds, *Jim Wells*	1939	690	0	594,156	476,643	32	3	1	31	0	29	2
141	Rhode, *McMullen*	1936	0	650	Gas	Gas	10	0	2	0	8		
142	Ricaby,[18] *Starr*	1937	150	0	83,089	57,635	14	5	1	9	0	1	8
143	Richard King, *Nueces*	1937	760	140	798,839	400,996	40	9	1	38	1	38	0
144	Rincon, *Starr*	1938	960	240[3]	928,185	903,655	53	48	4	48	1[3]	48	0
145	Rincon, North, *Starr*	1940	80	20	7,434	7,434	4	4	0	4	0	2	2
146	Rio Grande City, *Starr*	1932	150	60	400,342	21,962	30	0	4	15	0	0	15
147	Riverside, *Nueces*	1938	80	80[3]	60,420	30,491	5	0	1	2	1[3]	2	0
148	Robston, *Nueces*	1939	60	0	38,523	31,608	2	1	0	2	0	2	0
149	Roma, *Starr*	1927	20	280	21,408	2,243	5	0	0	1	0	1	0
150	Sacatosa, *Starr*	1938	0	10	Gas	0	1	0	1	0	0		

[18] Includes Rancho Solo extension.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.	Repressuring Operation[d]	Character of Oil	Producing Formation								Deepest Zone Tested to End of 1940	
	Initial		Gravity A.P.I. at 60°F., Weighted Average	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
119			20.7	Mirando	Eoc	S	Por	1,201	1,213	12	ML	Pettus	1,501
120	1,050		43-46.1	Pettus	Eoc	S	Por	4,683	4,822	8	ML	Cook Mt.	5,710
121			Gas	Frio	Olig	S	Por	3,132	3,138	6	AF	Frio	3,553
	925		26.4	Frio	Olig	S	Por	3,498	3,503	5			
122	2,650		38.2-57	Frio	Olig	S	Por	6,900	7,000	15	A	Frio	7,295
123	300		22	Mirando	Eoc	S	Por	1,880	2,025	12	ML	Yegua	3,151
	850		Gas	Cockfield	Eoc	S	Por	2,407	2,473	15			
124	900		30.6-32	Frio	Olig	S	Por	5,048	5,125	15	MF	Vicksburg	5,694
125			16	Catahoula	Olig	L	Cav	450	455	5	DS	Mt. Selman	5,454
	200		45	Jackson	Olig	S	Por	2,730	2,744	14			
126	1,100		Gas	Yegua	Eoc	S	Por	3,120	3,130	10	ML	Yegua	3,156
127	700		Gas	Frio	Olig	S	Por	1,915	1,932	17	MF	Caddell	3,620
128			Gas	Cole	Eoc	S	Por	1,750	1,760	5	ML	Yegua	3,309
	750		23.1	Govt. Wells	Eoc	S	Por	2,410	2,451	20			
			23.1	Mirando	Eoc	S	Por	2,610	2,635	15			
129	30		22.9	Govt. Wells	Eoc	S	Por	2,441	2,465	13	ML	Loma Novia	2,563
130			Gas	Govt. Wells	Eoc	S	Por	2,246	2,262	16	ML	Yegua	3,210
131	500		20	Cole	Eoc	S	Por	1,324	1,362	7	ML	Yegua	3,250
			21.7-22.7	Govt. Wells	Eoc	S	Por	1,950	2,080	12			
	400		20.4	Loma Novia	Eoc	S	Por	2,100	2,174	10			
132			13	Catahoula	Olig	S	Por	180	580	20	DS	Mt. Selman	5,902
	500		47	Hockleyensis	Eoc	S	Por	3,462	3,623	26			
133	2,200		31.4	Frio	Olig	S	Por	5,500	5,525	10	AF	Frio	7,253
	1,100		34.2	Frio	Olig	S	Por	5,650	5,675	12			
			31.6-62	Frio	Olig	S	Por	5,890	5,920	10			
	650		40	Frio	Olig	S	Por	6,156	6,159[20]	3			
134	1,950		Gas	Heterostegina	Olig	S	Por	4,808	4,836	20	AF	Frio	6,750
	1,800		Gas	Frio	Olig	S	28-34	5,110	5,136	15			
135	800		22.8	Catahoula	Olig	S	Por	2,250	2,350	10	D	McElroy	7,155
	900		24	Frio	Olig	S	Por	3,165	3,265	11			
136	1,800		54-60	Frio	Olig	S	Por	5,365	5,480	10	D	Jackson	8,162
	2,100		36-60	Frio	Olig	S	Por	5,625	6,138	10			
	2,000		38.1	Vicksburg	Olig	S	Por	6,582	6,694	10			
137			19.4	Cole	Eoc	S	Por	1,800	1,895	12	ML	Yegua	3,777
	800		Gas	Govt. Wells	Eoc	S	Por	2,555	2,569	14			
138			22.5	Cole	Eoc	S	Por	1,225	1,275	9	MF	Mt. Selman	5,222
139			16	Jackson-Cockfield	Eoc	S	Por	390	1,010	15	ML	Mt. Selman	3,247
140	2,750		31	Frio	Olig	S	Por	4,785	4,928	10	A	Jackson	6,025
	1,660		38	Frio	Olig	S	Por	5,100	5,254	9			
141	650		Gas	Cole	Eoc	S	Por	1,800	1,822	12	MF	Yegua	3,534
142	175		21.2	Frio	Olig	S	Por	1,270	1,324	8	ML	Jackson	2,844
	Pump		21.2	Frio	Olig	S	Por	1,432	1,456	5			
	235		30	Frio	Olig	S	Por	1,604	1,611	7			
143			22	Frio	Olig	S	Por	4,000	4,030	15	AF	Hockleyensis	7,567
	650		37	Frio	Olig	S	Por	5,250	5,270	7			
	1,250		39	Frio	Olig	S	Por	5,380	5,466	15			
	725		42	Vicksburg	Olig	S	Por	5,595	5,750	10			
	550		38	Vicksburg	Olig	S	Por	6,133	6,143	10			
144	1,500		39	Frio	Olig	S	Por	3,629	3,797	20	A	Yegua	6,862
			38-56	Frio	Olig	S	Por	3,855	4,022	18			
	1,700		45.1-54	Frio-Vicksburg	Olig	S	26-39	4,154	4,294	20			
145			44.6	Frio	Olig	S	Por	4,111	4,137	18	A	Jackson	5,590
			42.5	Frio-Vicksburg	Olig	S	Por	4,393	4,402	9			
	1,250		47.5	Jackson	Eoc	S	Por	5,478	5,590	15			
146			23	Frio	Olig	S	Por	1,350	1,450	8	MF	Jackson	3,258
147	1,450		32.2-51	Frio	Olig	S	Por	4,888	5,037	25	A	Vicksburg	7,750
148	300		41.9	Frio	Olig	S	Por	5,195	5,208	12	A	Frio	7,525
	950		51.9	Frio	Olig	S	Por	5,548	5,582	20			
149			Gas	Frio-Jackson	Olig-Eoc	S	Por	192	200	8	A	Reklaw	4,827
					Eoc	S	Por						
			35.2	Queen City	Eoc	S	Por	3,560	3,650	6			
150	400		Gas	Govt. Wells	Eoc	S	Por	1,650	1,661	11	ML	Govt. Wells	1,794

[20] Perforations.

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: End of 1940: Temporarily Shut Down	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Number of Oil and/or Gas Wells: End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940: Number of Wells: Flowing	Oil-production Methods, End of 1940: Number of Wells: Artificial Lift
151	Sam Fordyce,[19] *Starr, Hidalgo*	1934	1,600	900	7,814,282	444,291	256	0	65*y*	99	0	22	77
152	Sandia, *Jim Wells*	1929	50	120	22,719	1,215	6	0	3	1	0	0	1
153	San Diego *Jim Wells*	1934	0	120	Gas	0	2	0	0	0	0		
154	San Jose, *McMullen*	1938	10	10	450	0	2	0	1	0	0		
155	San Salvador, *Hidalgo*	1938	0	300[3]	85,306	41,785	3	2	0	0	3[3]		
156	Santo Domingo, *Starr*	1936	0	50	Gas	0	2	0	2	0	0		
157	Sarnosa, *Duval*	1932	690	180	2,392,856	154,010	57	0	5	41	0	0	41
	Saxet, *Nueces*												
158	Shallow	1923	3,850	3,800	45,676,847	5,252,615	759	3	20	355	35	118	237
159	Deep	1935	2,450	3,400[2]					30	149	46[2]	94	55
160	Seabury, *Starr*	1939	10	10	484	234	2	1	1	1	0	0	1
161	Sejita, *Duval*	1939	0	80[3]	1,800	1,360	2	1	2	0	0	0	0
162	Seven Sisters, *Duval*	1934	4,420	280	13,485,256	2,424,068	456	6	18	401	7	13	388
163	Seven Sisters, South, *Duval*	1937	330	0	See Seven Sisters		33	0	2	31	0	0	31
164	Shield, *Nueces*	1940	80	20[3]	21,787	21,787	4	4	1	3	0	3	0
165	Sinton, *San Patricio*	1934	225	100	85,835	3,567	7	0	1	1	1	1	0
166	Southland, *Duval*	1939	80	20	77,648	51,026	5	1	2	3	0	3	0
167	Stratton, *Nueces*	1931	350	1,000[3]	462,818	74,744	40	28	6	17	17[3]	17	0
168	Sullivan (South Agua Dulce), *Nueces*	1936	120	680[3]	99,773	7,640	7	0	5	1	1[3]	1	0
169	Sullivan City, *Hidalgo*	1939	400	160[2]	90,056	65,391	26	17	6	18	2	17	1
170	Sun, *Starr*	1938	900	100[3]	431,936	280,459	51	32	5	43	3[3]	40	3
171	Sweden, *Duval*	1937	200	160	265,012	22,406	13	1	6	5	0	2	3
172	Taft, *San Patricio*	1935	720	80	4,292,290	926,068	74	1	4	69	1	48	21

[19] Includes North Ricaby.

TABLE 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
151	400		21.5	Frio	Olig	S	Por	2,737	2,793	16	AF	Mt. Selman	9,708
	1,050		23.5	Frio	Olig	S	Por	2,831	2,890	22			
	1,250		24.9	Frio	Olig	S	Por	2,925	3,125	20			
	1,150		Gas	Frio	Olig	S	Por	3,183	3,196	13			
	2,800		Gas	Jackson	Olig	S	Por	5,840	5,900	20			
152	1,050		Gas	Catahoula	Olig	S	Por	2,910	2,917	7	AF	Hockleyensis	5,701
	1,227		38.3	Frio	Olig	S	Por	4,002	4,023	13			
	1,750		52	Cole	Eoc	S	Por	5,151	5,163	10			
153	1,200		Gas	Frio	Olig	S	Por	2,952	2,976	10	A	Yegua	6,480
154	245		23	Cole	Eoc	S	Por	1,147	1,163	16	ML	Yegua	2,370
155	3,200	PM	48.8–58	Frio	Olig	S	Por	7,315	7,645	15	A	Vicksburg	8,704
	3,875		49.7	Frio-Vicksburg	Olig	S	Por	8,174	8,704	15			
156	1,050		Gas	Frio	Olig	S	Por	2,461	2,616	25	A	Yegua	6,005
157			21.3	Govt. Wells	Eoc	S	Por	2,300	2,500	15	MF	Yegua	4,073
158	1,325		24	Lagarto-Oakville	Mio	S	Por	1,000	3,150	15	DF	Vicksburg	10,892
			24	Catahoula	Olig	S	Por	3,900	4,500	18			
			31.7	Discorbis-Het.	Olig	S	Por	4,700	4,880	18			
159	2,000		30.6–42.6	Frio	Olig	S	Por	5,280	6,900	20			
	2,300		56	Frio	Olig	S	Por	7,250	7,548	20			
	3,400		58	Frio-Vicksburg	Olig	S	Por	9,900	9,927	20			
160			22.6	Frio	Olig	S	Por	1,328	1,339	5	ML	Jackson	2,757
161	2,150		51.7	Govt. Wells	Eoc	S	Por	5,334	5,345	11	MF	Yegua	6,838
	750		52	Hockleyensis	Eoc	S	Por	5,476	5,675	15			
162	270		Gas	Frio	Olig	S	Por	1,232	1,262	15	MF	Cook Mt.	4,404
	225		21	Cole	Eoc	S	Por	1,710	1,720	10			
			20.5	Chernosky	Eoc	S	Por	2,112	2,225	20			
	625		23	Govt. Wells	Eoc	S	Por	2,470	2,485	15			
	200		27	Loma Novia	Eoc	S	Por	2,660	2,690	15			
	460		23	Mirando	Eoc	S	Por	2,540	2,565	10			
	1,200		Gas	Yegua	Eoc	S	Por	3,037	3,071	15			
163			21.5	Frio	Olig	S	Por	1,559	1,566	7	MF	Yegua	3,100
			23	Loma Novia	Eoc	S	Por	2,646	2,656	10			
164	925		44.3	Frio	Olig	S	Por	6,608	6,657	15	AF	Frio	7,806
	2,385		54–58	Frio	Olig	S	Por	6,970	6,980	10			
165	2,200		33.4–47	Frio	Olig	S	Por	5,415	5,437	15	A	Frio	7,438
	1,160		33	Frio	Olig	S	Por	5,880	5,905	10			
166	600		48.1	Pettus	Eoc	S	Por	5,286	5,298	10	MF	Yegua	6,015
	865		43.8	Cockfield	Eoc	S	Por	5,355	5,365	10			
167	1,850	PM	58	Frio	Olig	S	Por	4,788	4,801	13	DF	Vicksburg	7,206
	2,110		49.3	Frio	Olig	S	Por	5,992	6,002	10			
	1,900		42–54	Frio	Olig	S	Por	6,273	6,460	20			
	1,325		54	Frio	Olig	S	Por	6,480	6,607	17			
	700		43	Frio	Olig	S	Por	6,667	6,708	20			
168	2,000		51	Frio	Olig	S	Por	5,756	5,780	15	DF	Frio	6,912
	2,200		Gas and Distillate	Frio	Olig	S	Por	6,400	6,410	10			
	2,300		Gas and Distillate	Frio	Olig	S	Por	6,788	6,800	12			
169	1,100		24	Frio	Olig	S	Por	3,414	3,463	15	AF	Mt. Selman	9,708
	1,375		Gas	Frio	Olig	S	Por	3,936	3,983	25			
	700		43.6	Frio	Olig	S	Por	4,121	4,130	9			
170	1,800		52	Frio	Olig	S	Por	4,111	4,142	15	A	Jackson	5,926
	750		46–62	Frio	Olig	S	Por	4,610	4,673	15			
	730		45.2	Frio	Olig	S	Por	4,842	4,858	16			
	800		45.1	Frio	Olig	S	Por	4,900	4,972	10			
	2,000		47.9	Vicksburg	Olig	S	Por	5,115	5,135	20			
171	120		43	Chernosky	Eoc	S	Por	4,895	4,915	20	AF	Yegua	6,531
			46	Upper Govt. Wells	Eoc	S	Por	5,072	5,091	19			
	300		Gas	Lower Govt. Wells	Eoc	S	Por	5,100	5,116	16			
	710		43	Cockfield	Eoc	S	Por	5,845	5,869	24			
172	600		21.4	Catahoula	Olig	S	Por	3,975	4,010	20	DF	Frio	6,926
	650		21.6	Catahoula	Olig	S	Por	4,300	4,375	20			
	375		23.3	Heterostegina	Olig	S	Por	4,900	4,938	20			

Nueces County, and Baffin Bay, Kleburg County. These, together with already established offshore production in the Flour Bluff field, Nueces County, and Bird Island field, Kleburg County, now give South Texas a total of five fields producing from offshore.

Exploration in the Wilcox, limited to three tests in Webb County, none of which produced from this zone, and to a few wells in LaSalle County, one of which produced oil for a short time, did not obtain the production found in the Wilcox in other South Texas counties. The shows obtained on these few tests probably will encourage exploration in this formation. The Wilcox provided LaSalle County with its first oil production through the discovery of the Washburn field, but subsequent tests in this county have failed to provide commercial production. Further exploration of the Wilcox along the Washburn field trend probably will be extensive during the coming year. This belt will extend from Webb County northeastward following the Jackson and Yegua outcrops to the Sabine River. The South Texas district along this belt will receive its share of drilling.

One of the interesting discoveries of the year was the opening of the Willamar field, Willacy County. This structure, a geophysical find, is thought to be one of the largest ever found in South Texas. Little drilling has been done in Willacy County,

TABLE 1.—(*Continued*)

Line Number	Field, *County*	Year of Discovery	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift
173	Tarancahuas, *Duval*	1939	290	0	118,157	117,157	29	28	0	29	0	29	0
174	Tesoro (De Soto), *Duval*	1938	140	80	167,890	42,699	8	0	2	5	1	4	1
175	Thomas Lockhart, *Duval*	1937	100	0	17,146	0	4	0	4	0	0	0	0
176	Turkey Creek (West Saxet), *Nueces*	1938	890	40	2,995,993	933,400	60	0	2	56	2	39	17
177	Villa, *Zapata*	1932	0	120	Gas	0	3	0	0	0	0		
178	Volpe, *Webb*	1939	330	10	173,029	151,712	34	22	5	29	0	0	29
179	Wade City, *Jim Wells*	1939	1,540	160[3]	651,498	648,370	78	76	2	73	3	71	2
180	Washburn, *La Salle*	1940	10	0	2,500[y]	2,500[y]	1	1	0	1	0	1	0
181	Wentz, *McMullen*	1932	0	80	Gas	0	3	0	0	0	0		
182	Weslaco, *Hidalgo*	1938	0	40[3]	2,125	0	1	0	1	0	0		
183	White Point, *San Patricio*	1930	100	3,900	147,642	12,227	48	0	5	1	11	1	0
184	White Point, East, *San Patricio, Nueces*	1938	4,160	180[2]	5,290,065	2,974,477	235	74	2	229	4	214	15
185	Willamar, *Willacy*	1940	20	0	2,939	2,939	1	1	0	1	0	1	0
186	Woods, *Starr*	1936	0	120	Gas	0	4	0	0	0	0		
187	Wray, *Zapata*	1933	0	80	Gas	0	3	0	0	0	0		
188	Young (Charco Blanco), *Starr*	1938	0	20	Gas	0	1	0	0	0	1		
189	Yzaguirre, *Starr*	1940	20	20[3]	2,314	2,314	2	2	0	1	1[3]	1	0
190	Total		110,815	73,350	325,697,136	52,646,521	12,186	1,145	1,118	8,040	526	2,684	5,356

or in Cameron and Kenedy Counties, although much of the land has been under lease for several years and severe structures are supposed to have been uncovered by geophysical work. With expiration dates approaching on many leases, and with the new Willamar field serving as incentive, the near future should see increased drilling activity in these three Frio-trend counties.

South Texas oil production totaled 52,646,521 bbl. in 1940, against 55,105,506 bbl. in 1939.

Complete reference to the nomenclature of formations, producing horizons, trends, recycling possibilities, and other general geological and engineering information for this district is contained in the three earlier volumes of Petroleum Development and Technology (*Trans.* A.I.M.E., **127**, **132**, 136).

Duval County, Laredo District

East Peters Field.—Mortimer, Springer and Collins' W. R. Peters No. 3-B, sec. 196, two miles east of gas production in the Peters field, was completed on Jan. 14 to open this field from Government Wells sand at 2441 to 2465 ft. On a 3-hr. gauge the well jetted 36 bbl. of 22.9° gravity oil from perforations at 2450 to 2463 ft. through ⅜-in. choke, under 30 lb. tubing pressure and 260 lb. casing pressure.

Table 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.: Initial	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
173			21.1	Frio	Olig	S	Por	2,014	2,105	15	ML	Caddell	3,309
174			Gas	Pettus	Eoc	S	Por	4,828	4,848	15	NF	Yegua	5,541
	670		41.8–45	Pettus	Eoc	S	Por	5,080	5,136	20			
175	1,450		56.8	Pettus	Eoc	S	Por	4,659	4,672	13	MF	Yegua	5,502
176	550		22.6	Catahoula	Olig	S	Por	3,846	3,860	14	DF	Frio	7,511
	375		25	Catahoula	Olig	S	Por	4,025	4,080	10			
	875		43	Frio	Olig	S	Por	5,641	5,664	19			
	1,400		35	Frio	Olig	S	Por	5,794	5,872	19			
	780		28	Frio	Olig	S	Por	6,430	6,456	26			
177	375		Gas	McElroy	Eoc	S	Por	1,657	1,664	7	ML	Cook Mt.	3,000
178	Pump		22.5	Mirando	Eoc	S	Por	2,450	2,488	8	ML	Yegua	3,717
179	1,850		31–51	Frio	Olig	S	Por	4,772	4,820	10	MF	Jackson	5,411
	400		32.2	Vicksburg	Olig	S	Por	4,894	4,933	10			
	1,520		55	Vicksburg	Olig	S	Por	5,272	5,286	12			
180	50		42	Wilcox (Rockdale)	Eoc	S	Por	4,860	4,867	7	AF	Cretaceous	8,300
181	200		Gas	Cole	Eoc	S	Por	370	382	12	N	Yegua	1,654
182	2,950		51	Frio	Olig	S	Por	8,634	9,005	15	A	Vicksburg	9,182
183	765		Gas	Lagarto-Oakville	Mio	S	Por	1,900	2,800	10	AF	Frio	7,211
	2,000		24.8	Heterostegina	Olig	S	Por	4,880	4,961	10			
	500		29.8	Frio	Olig	S	Por	5,672	5,676	4			
184	500		Gas	Oakville	Mio	S	Por	2,495	2,505	10	AF	Vicksburg	8,383
	500		Gas	Catahoula	Olig	S	Por	3,960	4,015	10			
	1,050		26.8	Heterostegina	Olig	S	Por	4,930	4,952	20			
	950		38.7	Frio	Olig	S	24–33	5,630	5,680	30			
	850		59.4	Frio	Olig	S	Por	5,730	5,775	15			
	925		40.4	Frio	Olig	S	Por	5,850	5,862	12			
185	350		30	Frio	Olig	S	Por	7,620	7,678	15	A	Frio	9,003
186	460		Gas	Frio	Olig	S	Por	963	975	12	A	Jackson	3,360
187	150		Gas	Jackson	Eoc	S	Por	348	370	22	ML	Mt. Selman	2,000
188	960		Gas	Jackson	Eoc	S	Por	2,708	2,730	15	MF	Jackson	3,008
189	825		48.1	Frio	Olig	S	Por	4,610	4,620	10	A	Jackson	6,006
	2,125		56	Frio-Vicksburg	Olig	S	Por	5,234	5,246	12			
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TABLE 2.—*Summary of Drilling Operations in South Texas*

Important Wildcats and Semiwildcats Drilled in 1940

	County	Well Name and Location	Total Depth, Ft.	Surface Formation	Deepest Horizon Tested
	LAREDO DISTRICT				
1	Duval	W. R. Peters No. 3-B, sec. 196	2,557	Goliad	Govt. Wells
2	Duval	Rogers Estate No. 1-A, survey 21	4,335	Goliad	Pettus
3	Duval	M. Garcia No. 1, sec. 407	5,087	Goliad	Yegua
4	Duval	Lillie Kreis No. 1, I.G.N. survey 68	3,261	Goliad	Loma Novia
5	Duval	Drummond No. 2-B (Seven Sisters)	1,303	Goliad	Frio
6	Duval	Lundell No. 1, survey 364 (Lundell)	1,359	Goliad	Cole
7	Duval	Parr No. 1, sec. 298 (Blanchard)	5,710	Goliad	Cook Mt.
8	Duval	Rogers No. 1, survey 275 (Bridwell)	4,307	Goliad	Pettus
9	Duval	Driscoll No. 1-B (Conoco Driscoll)	4,515	Goliad	Yegua
10	Duval	D.C.R.C. No. 1, survey 289	2,212	Catahoula	Pettus
11	Duval	A. Weil No. 1, sec. 1 (Hoffman)	2,724	Goliad	Govt. Wells
12	Duval	Rodriguez No. 1 (Sejita)	6,838	Goliad	Yegua
13	Duval	Geo. Herberger No. 1-A, sec. 14 (Sweden)	5,873	Goliad	Cockfield
14	Duval	Salazar No. 1-B, survey 3 (Hoffman)	2,634	Goliad	Govt. Wells
15	Duval	Weiderkehr No. 70 (Govt. wells)	3,183	Goliad	Pettus
16	Duval	D.C.R.C. No. 10, survey 290	1,550	Catahoula	Mirando
17					
18	Jim Hogg	Wood No. 1, sec. 82	2,614	Catahoula	Pettus
19	Jim Hogg	E. L. Armstrong No. 1, sec. 90 (Holland-Hebbronville)	3,691	Goliad	Cockfield
20	Jim Hogg	Reuben Holbein No. 1, sec. 4	3,150	Goliad	Yegua
21	Jim Hogg	D. Gutierrez No. 1, sec. 579	3,156	Goliad	Yegua
22	La Salle	Washburn Ranch No. 1, survey 67	8,300	Yegua	Cretaceous
23	McMullen	Ezzell No. 99 (South Calliham)	1,197	Catahoula	Loma Novia
24	Starr	Davenport No. A-1, survey 6 (Rincon)	4,383	Goliad	Vicksburg
25	Starr	Slick-B-9, survey 266 (Rincon)	4,152	Goliad	Frio
26	Starr	Slick-B-26, survey 232 (Rincon)	4,311	Goliad	Vicksburg
27	Starr	M. F. Yzaguirre No. 1, survey 227	5,258	Goliad	Jackson
28	Starr	Lehr No. 1, sec. 513	5,542	Goliad	Jackson
29	Starr	Std. Trust No. 1, Porcion 92	3,505	Goliad	Frio
30	Starr	Seyfriedt No. 1, sec. 928 (Yzaguirre)	6,006	Goliad	Jackson
31	Starr	Rodriguez No. 1, (Kelsey)	7,507	Goliad	Yegua
32	Starr	Saentz-State No. 1, survey 80 (North Rincon)	5,590	Goliad	Jackson
33	Starr	Saentz-State No. 2 (North Rincon)	5,266	Goliad	Jackson
34	Starr	Slick No. 6-B, sec. 528 (Rincon)	4,866	Goliad	Vicksburg
35	Starr	Slick No. 2-A, sec. 485 (Rincon)	5,797	Goliad	Jackson
36	Starr	Slick No. 11-B, sec. 266 (Rincon)	4,278	Goliad	Frio-Vicksburg
37	Starr	Slick No. 17-A (Rincon)	5,248	Goliad	Jackson
38	Starr	Chapa de Vela No. 1 (Boyle)	4,503	Goliad	Jackson
39	Starr	Jaurez No. 1, Teresa grant (Kelsey)	5,638	Goliad	Vicksburg
40	Starr	Guerra No. 1, Porcion 69	3,096	Jackson	Mt. Selman
41	Starr	Ricaby No. 1, Porcion 81 (Ricaby)	1,770	Goliad	Frio
42	Starr	Seabury No. 1, Porcion 80 (Seabury)	1,349	Goliad	Frio
43	Starr	Green & Manning, No. 1, Porcion 81 (Hayden)	2,644	Goliad	Jackson
44	Webb	Lopez No. 46, survey 309	2,185	Catahoula	Mirando
45	Webb	Bruni No. 64, survey 446	1,880	Goliad	Cole
46	Webb	Pedro-Leal No. 2, sec. 461	3,117	Jackson	Pettus
47	Webb	A. M. Bruni No. 7 (Cole Bruni)	8,959	Goliad	Wilcox
48	Webb	A. M. Bruni No. 4 (Cole Bruni)	3,973	Goliad	Cook Mt.
49	Webb	Callaghan No. 1, sec. 585	9,501	Goliad	Wilcox
50	Zapata	Yeager Strohman No. 1 (Glen)	2,178	Jackson	Mirando
51	Zapata	Quinlan No. 1, Porcion 19 (Lopena)	2,262	Yegua	Queen City
	SOUTH CORPUS CHRISTI DISTRICT				
52	Hidalgo	Yturria No. 1, Porcion 43	3,138	Goliad	Frio
53	Hidalgo	Yturria No. 1-A, Porcion 44 (Nichols)	3,553	Goliad	Frio
54	Hidalgo	Chapa No. 1-A, Porcion 39 (Sullivan City)	4,130	Goliad	Frio
55	Hidalgo	Joseph Cardenas No. 2 (San Salvador)	8,704	Beaumont	Vicksburg
56	Jim Wells	Blaske No. 1, Agua Dulce grant	5,603	Lissie	Vicksburg
57	Jim Wells	Gallagher No. 1, Gallagher subd. block 21	5,624	Lissie	Vicksburg

TABLE 2.—(*Continued*)

Important Wildcats and Semiwildcats Drilled in 1940

	Drilled by	Initital Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	Mortimer, Springer & Collins	36 (3 hr.)		3/8	260	30	Opened East Peters field
2	Bridwell Oil Co.	122		3/16	1,500	1,175	Opened Bridwell field
3	Sun Oil Co.	11.5		Pump			Opened East Fitzsimmons field
4	Ike Howeth	38		2-in. tubing			Opened Kreis field
5	Reynolds & Richardson		3.5	3/4		270	New 1200-ft. Frio sand, Seven Sisters
6	Govt. Wells Oil Co.	23	13.8	2-in. tubing		430	Wildcat 6 miles NW. of Freer (Lundell field)
7	Taylor Rfg. & R. A. Thompson	45	1	1/8		1,250	Wildcat 3 miles NW. of Blanchard field (ext.)
8	Forest Development Co.	26	Gas	1/8	500	275	Extension Bridwell
9	Continental Oil Co.	118		1/4	630	80	East ext. Conoco Driscoll
10	Magnolia Petr. Co.		2.06	3/8			Discovery West Casa Blanca
11	Magnolia Petr. Co.		10			850	1/2 mile SW. ext. Hoffman
12	Std. of Texas	16	Gas	1/4		750	New sands and ext. Sejita
13	Hiawatha Oil & Gas Co.	60	Gas	5/32	1,900	1,820	Between Sweden and Benavides
14	Gilcrease Oil Co.	20	0.5	3/8	800	750	1 mile SW. ext. Hoffman
15	Sun Oil Co.	18.5	1.5	1/8		660	New 2900-ft. sand for Govt. wells
16	Magnolia Petr. Co.	75		3/8			Ext. Charasmousca
17							
18	Achning & Daubert	175	0.8	1/4	450	286	Opened Manila field
19	Texas Corporation	15	5	1/4	1,300	1,200	South ext. and new 3600-ft. Cockfield sd.
20	Guy A. Davis	85					Opened Holbein field
21	Patal Drillers et al.		25		1,100 (shut in)		Disc. Patal field
22	H. R. Cullen	113		3/8	650	50	Disc. Washburn
23	Edwin M. Jones		1.8	1/2			SE. ext. So. Calliham
24	W. R. Davis	201					New 3775-ft. sand
25	W. R. Davis	183					New 3725-ft. sand
26	W. R. Davis	66					New 3650-ft. sand
27	Complete Oil Well S. Co.	68	Gas	1/8	1,350	825	Opened Yzaguirre field
28	Sun Oil Co.	50 (fluid)	0.05				Opened North Rincon
29	Geo. R. Boyle et al.	100		7/64	1,475	1,000	Opened Boyle
30	W. R. Davis & Co.	50	3		2,125 (shut in)		New 5200-ft. sand, Yzaguirre
31	Sun Oil Co.	12	0.84	3/16	1,050	950	New 6400-ft. sand
32	Sun Oil Co.	70.7	1.6	7/64	1,825	1,250	New 5400-ft. Jackson sand
33	Sun Oil Co.						New 4400-ft. Vicksburg sand
34	W. R. Davis & Co.	122		1/2			New 3800-ft. Frio sand
35	W. R. Davis & Co.	46	3	3/8			New 4000-ft. sand
36	W. R. Davis & Co.	180				240	Another 3800-ft. Frio sand
37	W. R. Davis & Co.						New 3900-ft. sand
38	Barsodi Petr. Co.	86		1/8	1,135	590	New 3100-ft. Frio sand
39	Royal Oil & Gas Co	38	Gas	1/8	1,050	1,900	Opened 4600-ft. sand, Kelsey
40	T. E. Stephens		1	3/16			Opened Cook Mt. sand in Arroyo Grande
41	Bishop & Moss		Gas			600	Extension Ricaby
42	Denzil Oil Co.	25		Pump			Oil production and extension Seabury
43	Denzil Oil Co.		25				New 2600-ft. Jackson sand
44	Interstate Minerals	1,968					Opened Glen field
45	O. W. Killam	35	2.5	3/8		300	Opened south O'Hern field
46	W. C. McBride, Inc.	Spray	5	3/16	785	650	Opened McBride field
47	Tide Water Oil Co.	25	3	1/2		450	Deep test and new 5600-ft. Queen City sand
48	Highland Oil Co.	45.5		1/8	1,150	470	New 3900-ft. Cook Mt. sand
49	Sinclair-Prairie						Deep test. Dry
50	Jay Simmons	1,280		2-in. tubing	350	75	Extended Glen into Zapata Co.
51	E. A. Thompson		25			870	Extension Lopena
52	Royal Oil & Gas Co.		Blowout				Discovered Nichols field
53	Royal Oil & Gas Co.	87		1/8	1,350	925	Opened Nichols field
54	Royal Oil & Gas Co.	120		1/8	850	700	New 4100-ft. Frio sand
55	Gulf States Oil Co.	200	20	1/4	1,100	3,875	New deep sands 7322–8182 ft.
56	Henshaw Bros. & Atlantic	120		7/64	2,025	900	Opened Orange Grove
57	M. M. Miller & Sons	146		5/32	1,200	600	Opened Gallagher

Bridwell Field.—Bridwell field was opened on June 25 by Bridwell Oil Company's Rogers Estate No. 1-A, J. Poitevent survey 21, three miles southwest of the Fitzsimmons field. After a two weeks flow of gas, production turned into oil, gauging 122 bbl. of 43.6° gravity oil daily through $\frac{3}{16}$-in. choke under 1175 lb. tubing pressure and 1500 lb. casing pressure. Perforations were made at 4323 to 4325 ft. in a Pettus sand at 4321 to 4327 feet.

East Fitzsimmons Field.—Sun Oil Company's M. Garcia No. 1, A. B. and M. sec. 407, two miles east of Fitzsimmons production, opened this new field on May 18 when it pumped 11.5 bbl. of 43.7° gravity oil from perforations at 4901 to 4910 ft. in a Yegua sand at 4901 to 4916 feet.

Kreis Field.—Swabbing 38 bbl. of 29.2° gravity oil through 2-in. tubing, Ike Howeth's Lillie Kreis No. 1, I. G. N. survey

TABLE 2.—(*Continued*)

Important Wildcats and Semiwildcats Drilled in 1940

	County	Well Name and Location	Total Depth, Ft.	Surface Formation	Deepest Horizon Tested
58	Jim Wells	Thiel No. 1, G.C.F.T. subd. block 25	4,945	Lissie	Frio
59	Jim Wells	Grossman No. 1, Casa Blanca grant	5,785	Lissie	Vicksburg
60	Jim Wells	Wm. Koehler No. 1, Casa Blanca grant	5,068	Lissie	Frio
61	Jim Wells	Hornsby No. 1 (La Gloria-Recompletion)	7,227	Lissie	Vicksburg
62	Jim Wells	M. McNeil No. 2 (Wade City)	4,930	Lissie	Vicksburg
63	Jim Wells	Carver No. 1 (Wade City)	5,292	Lissie	Vicksburg
64	Jim Wells	A. Mueller No. 5 (Wade City)	4,928	Lissie	Vicksburg
65	Jim Wells	Whatley No. 2-A (Ben Bolt)	5,295	Lissie	Vicksburg
66	Jim Wells	M. W. Smith No. 1 (Ben Bolt)	5,600	Lissie	Vicksburg
67	Jim Wells	Muil No. 5 (Clark-Muil)	5,711	Lissie	Vicksburg
68	Jim Wells	Seeligson No. 14 (East Premont)	6,802	Lissie	Vicksburg
69	Jim Wells	Schroede No. 1 (Orange Grove)	5,096	Lissie	Frio
70	Jim Wells	Spoetzel No. 1 (Wade City)	4,814	Lissie	Frio
71	Jim Wells	Wendt No. 1 (Wade City)	4,940	Lissie	Vicksburg
72	Jim Wells	Gallagher No. 2 (Gallagher)	6,260	Lissie	Jackson
73	Jim Wells	Schumacher No. 1 (Wade City)	5,002	Lissie	Vicksburg
74	Jim Wells	Reynolds No. 1, Survey 209 (Magnolia City)	6,289	Lissie	Vicksburg
75	Jim Wells	Pundt No. 1, Wright survey (Wade City)	4,974	Lissie	Vicksburg
76	Kleburg	State No. 1, tract 385, Laguna-de-Los Olmos	9,428	"Submerged"	Frio
77	Kleburg	State No. 1, tract 169 (Bird Island)	7,572	"Submerged"	Frio
78	Nueces	State No. 1-D, tract 30, Laguna Madre	6,955	"Submerged"	Frio
79	Nueces	Moore No. 1, sec. 143	6,774	Beaumont	Frio
80	Neuces	Greene No. 1, sec. 6 (Stratton)	6,805	Beaumont	Frio
81	Nueces	Studer No. 1 (Robston)	7,525	Beaumont	Frio
82	Nueces	Bertram No. 1 (Stratton)	6,578	Beaumont	Frio
83	Nueces	Union Central No. 1 (Stratton)	7,168	Beaumont	Frio
84	Nueces	J. W. Howze No. 1, sec. 56 (Minnie Bock)	3,827	Beaumont	Catahoula
85	Nueces	Union Central No. 2 (Stratton)	6,532	Beaumont	Frio
86	Nueces	State No. 2, tract 974 (East White Point)	6,362	Beaumont	Frio
87	Nueces	Guaranty Title No. 1 (Agua Dulce)	7,227	Beaumont	Frio
88	Nueces	Allen & Gallagher No. 1 (Shield)	7,806	Beaumont	Frio
89	Nueces	Dabney No. 1, sec. 80	7,503	Beaumont	Vicksburg
90	Nueces	Chapman-Estate No. 1, sec. 78	7,628	Beaumont	Frio
91	Neuces	McCoy No. 2 (Agua Dulce)	7,050	Beaumont	Frio
92	Nueces	H. Flynn No. 5-B (South Clara Driscoll)	6,000	Beaumont	Frio
93	Nueces	Texas No. 1, survey 723 (Corpus Christi)	5,200	Beaumont	Heterostegina
94	Nueces	Sellers No. 1, sec. 204 (Stratton)	6,915	Beaumont	Frio
95	San Patricio	Baldwin No. 7, sec. 46 (East White Point)	5,696	Beaumont	Frio
96	San Patricio	E. A. Rachal No. 38 (East White Point)	6,315	Beaumont	Frio
97	San Patricio	Peoples & Nichols No. 1 (Aransas Pass)	7,604	Allivium	Frio
98	San Patricio	Hart No. 1, Burgess survey (Odem)	7,411	Beaumont	Vicksburg
99	San Patricio	Lovett No. 1, sec. 13 (East Mathis)	5,695	Beaumont	Vicksburg
100	San Patricio	Ivey No. 1, sec. K, Paul subd. (Midway)	6,503	Beaumont	Frio
101	San Patricio	San Antonio Loan No. 1, McAuley survey	7,539	Beaumont	Frio
102	San Patricio	W. Roots No. 1, sec. 26 (East Plymouth)	5,813	Beaumont	Frio
103	Willacy	Willamar Community No. 1, San Juan de Carricios grant	9,003	Beaumont	Frio

68, four miles east of the Loma Novia field, was brought in on Oct. 23 to open this field's production from perforations in a Loma Novia sand at 3249 to 3258 feet.

West Casa Blanca Field.—This area, considered to be an extension of the Casa Blanca field, was opened on Oct. 1 by Magnolia Petroleum Company's D.C.R.C. No. 1, Poitevent survey 289. Initial production was 2,000,000 cu. ft. of gas through 3/8-in. choke from a Jackson (Cole) sand at 994 to 1006 feet.

TABLE 2.—(*Continued*)

Important Wildcats and Semiwildcats Drilled in 1940

	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
58	H. R. Smith, Inc.	20 (fluid)		1/8		100	Discovered West Orange Grove
59	Henshaw Bros.	312		3/16	825	520	Opened Henshaw
60	H. R. Smith		Gas producer indicated 5,049–5,068 ft.				Wildcat 3 miles east of Orange Grove
61	Magnolia Petr. Co.	155		3/16	2,675	300	New 7000-ft. sand
62	Rodney Delange	191		3/16	800	400	New 4900-ft. sand
63	Hewitt & Daugherty	24	0.5	1/8	1,650	1,520	New 5200-ft. sand
64	Anderson Prichard Oil Co.	122		9/64		175	New 4900-ft. sand
65	Cimaron Oil Co.	140		1/4	850	625	New 4900-ft. sand
66	Earl Calloway	90			(Gas lift)		New 4800-ft. sand
67	Frank J. Gravis	5	2	9/64	1,900	1,750	New 5500-ft. sand
68	Magnolia Petr. Co.	265		11/64	1,975	1,650	NE. ext. East Premont
69	H. H. Howell	140		7/64	1,000	800	NE. ext. Orange Grove
70	Esves Oil Co.	110		1/8	900	400	North ext. Wade City
71	Henshaw Bros.	168		11/64	1,100	600	SW. ext. Wade City
72	M. M. Miller	Spray	Gas	5/32	1,650	1,330	New 5700-ft. Vicksburg sand
73	Smith & Mosser	108		1/8	850	420	Southwest extension
74	Pure Oil Co.		2				New 5500-ft. sand
75	Gilcrease Oil Co.	97					Crude in 4800-ft. sand (Pundt)
76	Skelly Oil Co.	136		1/4		1,225	Opened Baffins Bay
77	Pure Oil Co.	24		3/8			NE. ext. Bird Island
78	Humble O. & R. Co.	177		1/8		1,725	Opened East Flour Bluff
79	Fred W. Shield	152		1/8	1,050	925	Opened Shield field
80	Gulf Plains Corp.	200	20				North ext. Stratton
81	Richardson Petr. Co.	226		1/4		300	New 5200-ft. sand
82	Southern Minerals	76		3/32	1,250	900	Crude in distillate sand
83	S.E.W. Oil Corp.	160		1/8	1,060	700	New 6600-ft. sand
84	Wellington Oil Co.	61		5/32	680	140	Between Clara Driscoll and Minnie Bock
85	Baytex Oil Corp.	170		1/8	925	1,325	New 6500-ft. sand
86	Sinclair-Prairie	135		1/8		925	New 5800-ft. sand
87	Richardson Petr. Co.	165		1/8		1,750	East ext. & oil in distillate sand
88	Shield, Allen & Morris	153	1.5	5/32	2,525	2,385	Ext. North and new 6900-ft. sand
89	F. A. Gillespie & Sons	90	96	1/8	2,560	2,450	Opened East Agua Dulce
90	Seaboard Oil Co.	5	1.5	3/16	1,370	1,320	Opened East Luby
91	Richardson Petr. Co.	187		1/8	1,906	1,375	New 6800-ft. sand
92	Texas Conservative	119		11/64	780	375	New 5800-ft. sand
93	Humble O. & R. Co.		0.165	3/16		180	Extension
94	Conroe Oil Co.	161					New 6400-ft. sand (crude)
95	Houston Oil Co.	130		1/8	1,550	1,050	New 4900-ft. Het. sand
96	Republic Gas Co.	30	Gas	5/16	2,240	850	New 5700-ft. sand
97	Baytex Oil Co.	Oil	Gas		2,800	2,600	New 7400-ft. sand
98	Wood & Sharp	50		1/2		175	First crude in Odem
99	Seaboard Oil Co.	140		1/8	1,350	1,000	New 5600-ft. sand
100	Stanolind O. & G. Co.	97		1/8	860	530	North extension Midway
101	Sam Auld & Tex. Gulf Prod.		Blowout	9/64	1,350	1,100	Junked crater
102	Texon Royalty Co.		Gas	1/8	1,900	1,600	Southwest extension
103	Pan-American Prod. Co.	263		1/4	Sealed	350	Opened Willamar field

	In Proven Fields	Rank Wildcats
Number of wells drilling Dec. 31, 1940	112	22
Number of oil wells completed during 1940	1,048	22
Number of gas wells completed during 1940	60	3
Number of dry holes completed during 1940	212	311

TABLE 3.—*Deep Wells Drilled during* 1940

County	Location	Company and Well	Depth, Ft.	Last Formation	Results
LAREDO DISTRICT, WELLS DRILLED TO 6000 FEET AND BELOW					
Duval	Southland field	Hiawatha O. & G. Co. Southland No. 4-A	6,015	Yegua	Dry
Duval	Benavides field	Hiawatha O. & G. Co. Southland No. 22	6,005	Yegua	Dry
Duval	Benavides field	Henderson, Coquat, et al. M. Momeny Estate No. 1	6,025	Yegua	Dry
Duval	Sejita field	Standard of Texas. A. B. Rodriguez No. 1	6,838	Yegua	Oil
Duval	Wildcat, sec. 62	C. Andrade III. Miller No. 1	6,016	Yegua	Dry
Jim Hogg	Wildcat, 15 mi. SE. Hebbronville	Humble Oil & Ref. Co. Mestina No. 1 (3)	6,270	Mt. Selman	Dry
Jim Hogg	Wildcat	Humble Oil & Ref. Co. Mestina No. 3 (5)	6,383	Mt. Selman (y)	Dry
Jim Hogg	Wildcat, S. A. Baluarte grant	Humble Oil & Ref. Co. Mestina No. 4 (6)	6,042	Mt. Selman (y)	Dry
Jim Hogg	Wildcat	Humble Oil & Ref. Co. Mestina No. 5 (7)	6,000	Mt. Selman (y)	Dry
Jim Hogg	Wildcat, Santa Rita prospect	Humble Oil & Ref. Co. Mestina O. & G. No. 3	6,012	Mt. Selman (y)	Dry
Jim Hogg	Wildcat, 7 mi. east Hebbronville	Humble Oil & Ref. Co. Mestina O. & G. No. 4	6,025	Yegua (y)	Dry
Jim Hogg	Wildcat, C. & M. survey 389	Humble Oil & Ref. Co. Mestina No. 4 (2)	6,406	Mt. Selman	Dry
Starr	Wildcat, 6 mi. NW of Sun	Magnolia Petr. Co. Yzaguirre No. 2	6,814	Yegua	Dry
Starr	Extension Sun field	Sun Oil Co. Rodriguez No. 1	7,507	Cook Mt.	Gas
Starr	Yzaguirre field	W. R. Davis. Seyfriedt No. 1	6,006	Yegua	Oil and gas
Starr	Wildcat, Santa Cruz grant	Magnolia Petr. Co. F. B. Guerra No. 3	6,640	Vicksburg	Dry
Starr	Wildcat, Porcion 87	Marr & Brown. Bass No. 1	6,087	Yegua	Dry
Webb	Cole Bruni	Tide Water. Bruni No. 7	8,959	Wilcox	Dist. and gas
Webb	Wildcat, sec. 585	Sinclair-Prairie. Callaghan No. 1	9,501	Wilcox	Dry
Webb	Cole Bruni	Tide Water. Bruni No. 8	10,295	Wilcox	Dry
SOUTH CORPUS CHRISTI DISTRICT, WELLS DRILLED TO 7750 FEET AND BELOW					
Brooks	Wildcat, survey 31	West Prod. Co. Cage No. 1	8,518	Vicksburg	Dry
Brooks	Wildcat, sec. 16, 5 mi. N. of Encino	Sun Oil Co. Boedecher-State No. 1-A	8,748	Jackson	Dry
Brooks	Wildcat, Loma Blanca grant	West Prod. Co. Ehlers No. 1	8,824	Vicksburg	Dry
Cameron	Wildcat, Santa Isbell grant	Sal Vieja Oil Co. & Pure Oil Co. Garcia No. 1	10,307	Vicksburg	Dry
Hidalgo	Wildcat, Porcion 64 4½ mi. SW McAllen	Humble Oil & Ref. Co. Ogg No. 1	8,695	Vicksburg	Dry
Hidalgo	San Salvador field	Gulf States Oil Co. Cardenas No. 2	8,702	Vicksburg	Oil and gas
Hidalgo	San Salvador field	Gulf States Oil Co. C. C. de Cavazos No. 1	8,004	Frio	Oil and gas
Hidalgo	Wildcat, Missouri Texas Land subd.	Humble Oil & Ref. Co. American Life No. 1	8,524	Vicksburg	Dry
Kleburg	Wildcat, Rincon de Santa Gertrudus grant	Humble Oil & Ref. Co. Mork No. 1	7,920	Frio	Dry
Kleburg	Baffins Bay field (disc.), tract 385	Skelly Oil Co. State No. 1	9,428	Frio	Oil
Nueces	Saxet field	Hiawatha O. & G. Co. Smith No. 8-B	10,892	Vicksburg	Oil and gas
Nueces	Wildcat, F. B. & E. subd.	Humble O. & R. Co. Duncan No. 1	8,050	Frio	Dry
Nueces	Wildcat, sec. 159	Continenal Oil Co. Davis No. 1	8,027	Frio	Dry
Nueces	Wildcat, survey 194	Pure Oil Co. Little No. 1	8,957	Frio	Dry
Nueces	Shield field	Allen & Morris. Allen & Gallagher No. 1	7,806	Frio	Oil and gas
Nueces	East Flour Bluff field	Humble Oil & Ref. Co. State No. 3-E	8,395	Frio	Dry
Nueces	Riverside field	Stanolind Oil & Gas Co. Thompson No. 2	7,750	Frio	Dist. and gas
San Patricio	Aransas Pass field	H. H. Howell. Gilchrist No. 1	8,356	Frio	Oil
San Patricio	Wildcat, Wm. Bell survey	Tide Water and Sinclair. Ragsdale Bros. No. 1	7,817	Frio	Dry
San Patricio	Aransas Pass field	Southern Minerals. Carlock No. 5	8,750	Frio	Oil and gas
Willacy	Willamar field (discovery)	Pan American Oil Co. Willamar Community No. 1-A.	9,002	Frio	Oil

TABLE 4.—*Total Number of Wells Drilled in South Texas Fields during* 1940

Field	Distillate or Oil	Gas	Dry
LAREDO DISTRICT			
Duval County			
Benavides	0	1	3
Bridwell	5	0	2
Bruni	0	0	1
Casa Blanca[1]	7	2	7
Cedro Hill	47	4	7
Charamousca	1	0	0
Chiltipin	1	0	3
Conoco Driscoll	16	0	5
Fitzsimmons	2	0	0
East Fitzsimmons	1	0	0
Government Wells	1	0	3
Hoffman	31	4	13
Kreis	1	0	0
Loma Novia	0	0	1
Longhorn	7	0	1
Lundell	25	2	7
Muralla (Blanchard)	1	1	1
O'Hern	0	0	1
Peters	0	1	2
East Peters	3	0	1
Piedre Lumbre	2	0	2
Piedras Pintas	0	0	2
Rancho Solo	6	0	4
Sejita	1	0	0
Seven Sisters	2	4	2
Southland	0	1	1
Sweden	1	0	0
Tarancahuas	28	0	5
Tesoro	0	0	1
Total	189	20	75
Jim Hogg County			
Colorado	96	2	1
Henne-Winch-Farris	0	0	1
Holbein	1	0	0
Holland-Hebbronville (Gutierrez)	1	0	2
Kelsey	2	0	2
Las Animas	0	0	1
Manila	13	0	3
Patal	0	1	0
Total	113	3	10
La Salle County			
Washburn (total for county)	1	1	0
McMullen County			
Calliham	4	0	8
Jacobs	0	0	1
Munson	3	0	2
San Jose	0	0	1
Total	7	0	12
Starr County			
Arroyo Grande	0	1	0
Barbacoas	0	1	2
Boyle	8	0	4
El Tanque	2	0	3
Hayden	0	1	0
Los Olmos	1	0	0
Kelsey	8	1	2
Ricaby	4	1	3
Rincon	47	1	5
North Rincon	4	0	0
Seabury	1	1	1
Sun	32	1	2
Yzaguirre	2	0	1
Total	109	8	23
Webb County			
Adami	52	1	2
Aviators	0	0	1
Bruni	1	1	3
Carolina-Texas	0	1	1
Cole West	7	0	7
Glen	40	3	3
McBride	0	1	0
O'Hern	0	1	0
South O'Hern	1	1	0
Oilton	1	0	0
Volpe	21	1	5
Total	123	10	22
LAREDO DISTRICT (CONTINUED)			
Zapata County			
Charco Redondo	0	0	4
Comitas	5	0	0
Cuellar	0	0	1
Escobas	11	1	4
Glen	5	0	0
Jennings	3	1	1
Lopeno	0	1	0
Mirando Valley	27	1	7
Total	51	4	17
Grand total, Laredo District	593	45	160
SOUTH CORPUS CHRISTI DISTRICT			
Brooks County			
Alta Verde	0	0	1
Kelsey	21	0	3
Total	21	0	4
Hidalgo County			
Nichols	1	0	0
San Salvador	2	0	0
Sullivan City	17	0	3
Total	20	0	3
Jim Wells County			
Alfred	13	0	4
Ben Bolt	28	0	4
Clark-Muil	0	1	1
Gallagher	3	0	2
Henshaw	1	1	0
Magnolia City	5	2	0
Orange Grove	19	0	4
Premont	18	0	0
East Premont	1	0	0
Reynolds	3	0	2
Sandia	0	0	1
Tom Graham (East Alice)	3	0	1
Wade City	74	2	4
Total	168	6	23
Kleburg County			
Baffins Bay	1	0	0
Bird Island	1	0	0
Total	2	0	0
Nueces County			
Agua Dulce	16	2	2
East Agua Dulce	1	0	0
North Agua Dulce	0	0	1
Clara Driscoll	4	1	0
South Clara Driscoll	29	1	2
Corpus Christi	0	1	0
East Flour Bluff	10	0	1
Luby	1	0	1
East Luby	1	0	0
North Luby	1	0	0
Minnie Bock	16	0	2
Richard King	9	0	1
Riverside	0	1	0
Robston	1	0	1
Saxet	3	0	1
Shield	4	0	0
Stratton	28	0	0
East White Point	23	2	0
Total	147	8	12
San Patricio County			
Aransas Pass	51	0	2
East Mathis	1	0	1
Midway	9	0	3
Odem	1	0	0
Plymouth	7	2	1
East Plymouth	0	1	0
Taft	1	0	0
White Point	0	0	1
East White Point	48	1	2
Total	118	4	10
Willacy County			
Willamar (total for county)	1	0	0
Grand total, Corpus Christi District	477	18	52
Grand total for South Texas fields[2]	1070	63	212

[1] Includes West Casa Blanca.
[2] Also one oil well in Live Oak portion of Ezzell field, and 15 oil wells and one dry hole in Aransas County portion of Aransas Pass field.

New Sands in Existing Fields, Duval County

Seven Sisters Field.—Reynolds and Richardson's Drummond No. 2-B, sec. 308, one mile northwest of the Seven Sisters field, was completed in a Frio sand at 1232 to 1262 ft. for a flow of 3,500,000 cu. ft. of gas daily through ¾-in. choke under 270 lb. pressure. Perforations were made at 1233 to 1244 feet.

Sejita Field.—Standard Oil Company of Texas' Rodriguez No. 1 well, ¾ mile north and slightly west of the field's discovery well, was completed on March 12 for a flow of gas with 16 bbl. of 52° gravity distillate through ¼-in. choke under 750 lb. tubing pressure, casing sealed. Production was obtained through four sets of perforations (5647 to 5660 ft., 5569 to 5581 ft., 5524 to 5560 ft., and 5476 to 5480 ft.) in a Hockleyensis distillate sand series between 5476 to 5675 ft. The well had also found a Yegua sand, which showed gas and distillate at 6790 to 6838 ft. (total depth).

TABLE 5.—*Rank Wildcats (New Field Discoveries) Completed during* 1940

County	Oil	Crude/or Distillate and Gas	Gas	Dry Holes
LAREDO DISTRICT				
Duval	4	0	1	62
Jim Hogg	2	0	1	28
LaSalle	1	0	0	6
McMullen	0	0	0	28
Starr	2	1	0	25
Webb	1	1	1	45
Zapata	0	0	0	28
Total	10	2	3	222
Average, one new field for every 16 rank wildcats.				
SOUTH CORPUS CHRISTI DISTRICT				
Brooks	0	0	0	5
Cameron	0	0	0	3
Hidalgo	1	0	0	7
Jim Wells	3	0	0	29
Kenedy	0	0	0	0
Kleburg	1	0	0	1
Nueces	2	2	0	26
SanPatricio	0	0	0	18
Willacy	1	0	0	0
Total	8	2	0	89
Average, one new field for every 10 rank wildcats.				
Grand total South Texas	18	4	3	311

Government Wells Field.—Sun Oil Company's Weiderkehr No. 70, survey 359, flowed much gas along with 186 bbl. of oil from perforations at 2982 to 2985 ft. in a Pettus sand. Flow was through ⅛-in. choke under 660 lb. tubing pressure. Gas-oil ratio was 8325:1.

Conoco Driscoll Field.—Continental Oil Company's Driscoll No. 1-B, B. S. and F. survey 481, was completed for a flow of 118 bbl. of 23° gravity oil from perforations at 2530 to 2535 ft. in a Jackson (Cole) sand. This well, a southeast extension to the field, is thought to have opened a new sand level.

JIM HOGG COUNTY, LAREDO DISTRICT

Manila Field.—Daubert and Achning's Wood No. 1, sec. 82, one mile west of the Randado field, was completed on June 5 to open this field from Pettus sand at 2603 to 2613½ ft. Flow of 175 bbl. of 24.9° gravity oil was obtained through ¼-in. choke under 286 lb. tubing pressure and 450 lb. casing pressure. Gas-oil ratio was 700:1.

Patal Field.—Patal field was discovered on July 14, by Patal Drillers and C. B. Peters Inc.'s D. Guitierrez No. 1, sec. 579, five miles northwest of Randado production. The well gauged 25,000,000 cu. ft. of gas on open flow from perforations at 3124 to 3127 ft. in a Yegua sand at 3120 to 3130 ft.; shut-in pressure was 1100 lb. Mirando was topped at 2423 ft., Pettus at 2836 ft. and Yegua at 3008 feet.

Holbein Field.—Guy A. Davis' Holbein (McLean) No. 1, sec. 4, Holbein subdivision, flowed 85 bbl. of 26° gravity oil to open this field from a Pettus sand at 2795 to 2811 ft. on Oct. 1.

New Sands in Existing Fields, Jim Hogg County

Holland-Hebbronville (Gutierrez) Field.—On Sept. 14, the Texas Company's E. L.

Armstrong No. 1, sec. 90, 6000 ft. south of the field's discovery well, opened Cockfield production for this area from sand at 3618 to 3656 ft. The well flowed 5,000,000 cu. ft. of gas and 15 bbl. of 55° gravity clear distillate through ¼-in. choke, under 1200 lb. tubing pressure and 1300 lb. casing pressure.

La Salle County, Laredo District

Washburn Field.—H. R. Cullen's Washburn Ranch No. 1, survey 67, eastern La Salle County, flowed 113 bbl. of 41.5° gravity oil from perforations at 4860 to 4867 ft. in the Wilcox, which was topped at 3612 ft. Flow was under 50 lb. on tubing and 650 lb. on casing. Before completion, on Sept. 17, the well had been drilled to 8300 ft. and had tested a gas sand at 4740 to 4829 ft., and sands showing oil at 5060 to 5067 ft. and 5417 to 5425 feet.

Starr County, Laredo District

Yzaguirre Field.—Complete Oil Well Service, Inc.'s M. F. Yzaguirre No. 1, survey 227, two miles east of Rincon, flowed 68 bbl. of 48.1° gravity oil on Aug. 14 to open this field from perforations at 4612 to 4618 ft. in a Frio sand at 4610 to 4620 ft.; pressures were 825 lb. on tubing and 1350 lb. on casing. Previous perforations at 4896 to 4904 ft. and 4716 to 4726 ft. each resulted in showings of gas and distillate.

W. R. Davis' Seyfriedt No. 1, sec. 928, flowed 3,000,000 cu. ft. of gas and 50 bbl. of 56° gravity distillate from perforations in a Vicksburg sand at 5234 to 5246 ft. Closed in pressure was 2125 lb.; total depth 6006 ft. in the Jackson.

North Rincon Field.—North Rincon field was opened on June 3 by Sun Oil Company's Lehr No. 1, sec. 513. It gauged 50 bbl. of fluid per hour, 75 per cent 44.6° gravity oil, along with gas, from perforations at 4127 to 4137 ft. in a Frio sand at 4127 to 4178 feet.

Transwestern Oil Company's and Rowan and Hope's Cameron No. 1, sec. 228, completed in May 1939 as the supposed discovery of the North Rincon field, is now considered to be in the rapidly expanding Rincon field.

A Vicksburg sand was opened on Oct. 7 by Sun Oil Company's Mateo-Saenz No. 1, survey 80. This well flowed 70.7 bbl. of 47.5° gravity oil with gas daily through

TABLE 6.—*Texas Railroad Commission Production Schedule for* 1940

Month	Number of Producing Days	Number of Shut-in Days
January	18	13
Feburary	29	0
March	31	0
April	29	1
May	30	1
June	27	3
July	24	7
August	22	9
September	21	9
October	22	9
November	21	9
December	21	10
Total	295	71

7⁄64-in. choke under 1250 lb. tubing pressure and 1825 lb. casing pressure. Perforations were made at 5478 to 5481 ft. in sand at 5478 to 5517 feet.

The same company's Mateo-Saenz No. 2, survey 80, produced 125 bbl. of 42.5° gravity oil daily from another Frio sand at 4398 to 4402 feet.

Boyle Field.—George R. Boyle's Standard Trust Company No. 1, Porcion 92, three miles east of Barbacoas field, flowed 100 bbl. of 44° gravity oil through 7⁄64-in. choke under 1000 lb. tubing pressure and 1475 lb. casing pressure, to open this field from perforations at 3491 to 3498 ft. in a Frio sand at 3490 to 3498 ft. This well was completed on June 6.

Borsodi Petroleum Company's Chapa de Vela No. 1, Porcion 92, extended the producing area one mile south and opened a second Frio level at 3159 to 3179 ft. on Sept. 14. A flow of 86 bbl. of 47.7° gravity oil was obtained from perforations at

3167 to 3175 ft. through ⅛-in. choke, under 590 lb. tubing pressure and 1135 lb. casing pressure.

New Sands in Existing Fields, Starr County

Kelsey Field.—Royal Oil and Gas Company's E. Jaurez No. 1, Santa Teresa grant, 6200 ft. southwest of production, was completed on March 20 from perforations at 4675 to 4680 ft. in Frio sand at 4671 to 4689 ft. The well flowed 38 bbl. of 52° gravity distillate along with much gas through ⅛-in. choke, under 1900 lb. tubing pressure and 1050 lb. casing pressure. A higher sand, tested through perforations at 4510 to 4515 ft., showed a large volume of gas along with salt water. The total depth of this well is 5638 feet.

Sun Oil Company's E. Rodriguez No. 1, Santa Teresa Grant, was completed on May 14 for a flow of 840,000 cu. ft. of gas and 12 bbl. of 55° gravity distillate from perforations at 6420 to 6427 ft. in a Jackson sand at 6421 to 6440 ft. Pressures were 950 lb. on tubing and 1050 lb. on casing.

Rincon Field.—W. R. Davis and Co. opened the following Frio Sands in this field:

Slick No. 6-B, sec. 528, jetted 122 bbl. of 38° gravity oil daily from perforations at 3855 to 3868 ft. in sand at 3855 to 3874 feet.

Slick No. 2-A, sec. 485, flowed 3,000,000 cu. ft. of gas with 46 bbl. of 56° gravity distillate daily from perforations at 3995 to 4022 feet.

Slick No. 11-B, sec. 266, flowed 180 bbl. of 39.8° gravity oil daily under 240 lb. working pressure from perforations at 3872 to 3878 feet.

Slick No. 17-A flowed oil from sand at 3958 to 3973 feet.

Slick No. 9-B, survey 266, flowed 183 bbl. of 39.6° gravity oil daily from perforations at 3727 to 3732 feet.

Slick No. 26-B, survey 232 flowed 66 bbl. of 39° gravity oil daily from sand at 3629 to 3653 feet.

Davenport No. 1-A, survey 6, flowed 201 bbl. of 39.2° gravity oil daily from sand at 3770 to 3797 feet.

Hayden Field.—Denzil Oil Company's Green and Manning No. 1, Porcion 81, was completed on May 23 for a flow of 25,000,000 cu. ft. of gas from a Jackson sand at 2619 to 2644 feet.

Arroye Grande Field.—T. E. Stephen's Guerra No. 2, Porcion 69, share 253, discovered a new producing level for this area, located 14 miles northwest of Roma, when it was completed for a flow of 1,000,000 cu. ft. of gas through 3/16-in. choke from perforations in a Cook Mountain sand at 2148 to 2161 ft. The total depth of this well is 3096 ft. in the Mount Selman.

Webb County, Laredo District

Glen Field.—Interstate Minerals, Inc.'s Lopez No. 46, survey 309, 3½ miles northeast of the Mirando Valley field of Zapata County, flowed 1968 bbl. of 21.8° gravity crude on April 26 to open this field from perforations at 2178 to 2185 ft. in a Mirando sand at 2173 to 2185 ft. This field was quite active during the year.

McBride Field.—W. C. McBride, Inc.'s Pedro Leal No. 2, sec. 461, 2½ miles west of the Cole field was completed for a flow of 5,000,000 cu. ft. of gas with a small spray of oil through 3/16-in. choke to open this field on June 1. Production was from perforations at 2529 to 2530½ ft. in a Mirando sand at 2525 to 2539 ft. under 650 lb. tubing pressure and 785 lb. casing pressure.

South O'Hern Field.—O. W. Killam's A. M. Bruni No. 64, survey 446, opened this field in January when it flowed 2,500,000 cu. ft. of gas with a spray of 35 bbl. of 22° gravity oil through ⅜-in. choke from perforations at 1802 to 1806 ft. in Cole sand at 1796 to 1811 ft., under 300 lb. working pressure. This well is 2 miles south of the O'Hern area.

New Sands in Existing Fields, Webb County

Bruni Field.—Tide Water Oil Company's A. M. Bruni No. 7, sec. 7, Arispe grant, was completed for a flow of 3,000,000 cu. ft. of gas and 25 bbl. of 46° gravity distillate, under 450 lb. working pressure, on Jan. 20. Completion was affected in a Queen City (Mt. Selman) sand at 5617 to 5675 ft. through perforations at 5655 to 5665 ft. In 1939 it attempted to blow out while in the Wilcox at 8959 feet.

Highland Oil Company's A. M. Bruni No. 4, sec. 7, originally completed as a producer in a Yegua sand at 3412 ft., was deepened and recompleted on Dec. 2 in a Cook Mountain sand at 3938 to 3950 ft. The initial production was 45.5 bbl. of 44° gravity oil through ⅛-in. choke under pressures of 470 lb. on tubing and 1150 lb. on casing.

Zapata County, Laredo District

Glen Field Extension.—The Glen field was extended one mile south into Zapata County by Jay Simmond's Yeager-Strohman No. 1, sec. 258. The well flowed 1280 bbl. of crude daily through open 2-in. tubing from the regular Mirando sand at 2172 to 2178 ft. Pressures were 75 lb. on tubing and 350 lb. on casing. Oil-gas ratio was 200:1.

Hidalgo County, South Corpus Christi District

Nichols Field.—Royal Oil and Gas Company's Yturria No. 1, 7500 ft. east of Sam Fordyce production, discovered the Nichols area when it blew out from a Frio sand at 3132 to 3138 ft. The field was established as productive on Aug. 28 by the same company's Yturria No. 1-A, 427 ft. east of No. 1, when it produced 87 bbl. of 38° gravity oil from perforations at 3497 to 3502 in another Frio sand at 3493 to 3503 feet.

New Sands in Existing Fields, Hidalgo County

Sullivan City Field.—Royal Oil and Gas Company's Chapa No. 1-A, share 238, Porcion 39, added a new producing level to this field when it flowed 120 bbl. of oil from perforations at 4122 to 4126 ft. in Frio sand at 4121 to 4130 ft. Pressures were 700 lb. on tubing and 850 lb. on casing.

San Salvador Field.—New deep sands were established in San Salvador field by Gulf States Oil Company's Josefa Cardenas No. 2, share 156, ⅜ mile northeast of production, when it flowed 200 bbl. of 48.8° to 49.7° gravity distillate and 20,000,000 cu. ft. of gas daily from perforations at 8174 to 8182 ft. and 7315 to 7350 ft. in Frio sands. Production was obtained through ¼-in. choke, under pressures of 3875 lb. on tubing and 1100 lb. on casing.

Jim Wells County, South Corpus Christi District

Orange Grove Field.—Henshaw Bros. and Atlantic Refining Company's Blaschke No. 1 was completed on May 4 for a flow of 120 bbl. of 31.8° gravity oil, from a Frio sand at 5088 to 5103 ft. through perforations at 5100 to 5103 ft., 1½ miles southeast of Wade City production. The tubing pressure was 900 lb. and casing pressure, 2025 lb. The well found the Wade City horizons about 300 ft. low, and later developments proved the presence of a subsurface fault trending in a northeast-southwest direction between the two fields, extending through the Orange Grove townsite. Production in both fields has been extended and now the two areas join along the fault line. The Wade City field occupies the upthrown northwest side and Orange Grove the downthrown southeast side of the fault. Several Orange Grove completions have been made in the Pundt sand (Wade City discovery Frio

sand), which is found about 50 ft. structurally below the field's discovery Blaschke sand.

Henshaw Field.—Henshaw Brother's Grossman No. 1, three miles southeast of the Orange Grove townsite, was completed in a thin Frio sand through perforations at 5139 to 5144 ft. for a flow of 312 bbl. of 31.1° gravity oil. It opened the Henshaw field on Oct. 3. Pressures were 520 lb. on tubing and 825 lb. on casing.

Gallagher Field.—M. M. Miller and Sons' Gallagher No. 1, block 21, Gallagher subdivision, 4 miles southeast of Sandia, was completed on June 7 in basal Frio sand at 5189 to 5215 ft. through perforations at 5189 to 5207 ft. for a flow of 146 bbl. of 39° gravity oil. Production was under 600 lb. tubing pressure and 1200 lb. casing pressure.

The company's Gallagher No. 2, 1511 ft. southeast of No. 1, was completed on July 19 in a Vicksburg sand at 5744 to 5761 ft. The flow was 88 bbl. of 41.5° gravity oil with gas from perforations at 5755 to 5757 ft., under 1330 lb. tubing pressure and 1650 lb. casing pressure.

New Sands in Existing Fields, Jim Wells County

La Gloria Field.—Magnolia Petroleum Company's Horusby No. 1, originally completed in 1939 in Frio sand at 6085 to 6091 ft., was recompleted in another Frio sand from new perforations at 7066 to 7080 ft. Production was 155 bbl. of 38.5° gravity oil through 3/16-in. choke under 300 lb. tubing pressure and 2675 lb. casing pressure. Original depth was 7227 ft. in the Vicksburg.

Magnolia City Field.—Pure Oil Company's Reynolds No. 1, A. B. and M. survey 209, flowed 2,000,000 cu. ft. of gas from Frio sand at 5561 to 5569 feet.

Wade City Field.—Rodney Delange's Maggie McNeil No. 2 flowed 191 bbl. of 31.8° gravity oil daily from perforations at 4923 to 4929½ ft. in a Vicksburg sand at 4920 to 4930 ft. Pressures were 400 lb. on tubing and 800 lb. on casing. Through this well was provided the field's first crude production, since previous production had been obtained from a Frio sand about 100 ft. structurally higher, and locally known as the Pundt sand. The new Vicksburg sand is locally identified as the McNeil sand.

Hewitt and Dougherty's Carver No. 1, I.G.N. survey 176, opened another Vicksburg sand and extended the field's production 1½ miles southwest when it flowed 534,000 cu. ft. of gas and 24 bbl. of 55° gravity distillate from sand at 5272 to 5286 ft. through perforations at 5276 to 5286 ft. Pressures were 1520 lb. on tubing and 1650 lb. on casing.

A Vicksburg sand locally known as the Alice sand, usually found about 12 ft. structurally below the McNeil sand, was opened on Sept. 23 by Anderson Prichard Oil Corporation's A. Mueller No. 5, Schleicher subdivision. This well flowed 122 bbl. of 32° gravity oil from sand at 4902 to 4928 ft. under 175 lb. working pressure.

First crude production for the Pundt Frio sand was provided by Gilcrease Oil Company's Pundt No. 1. This well, in Wright survey, was completed on June 24 for a flow of 97 bbl. of 31° gravity oil from sand at 4813 to 4819 feet.

East Premont Field.—Magnolia Petroleum Company's E. E. Seegligson No. 14, Los Jaboncillos grant, was completed on Dec. 18 for a flow of 265 bbl. of 38.4° gravity oil to open a Vicksburg sand at 6667 to 6697 feet.

Ben Bolt Field.—Cimarron Oil Company's D. Whatley No. 2-A, Whitman survey, flowed 140 bbl. of oil daily under 625 lb. tubing pressure and 850 lb. casing pressure, to open a Frio sand at 4906 to 4920 ft. Perforations were made at 4912 to 4918 feet. Another Frio level, at 4863 to 4875 ft., was opened by Earl Calloway's M. W. Smith No. 1, which produced 90 bbl.

of 30° gravity oil daily on gas lift from perforations at 4863 to 4870 feet.

Clark-Muil Field.—A Vicksburg sand at 5557 to 5572 ft. was found productive by Frank J. Gravis's Muil No. 5. A flow of 2,000,000 cu. ft. of gas with a spray of 5 bbl. of distillate, under 1750 lb. tubing pressure and 1900 lb. casing pressure was obtained through perforations at 5558 to 5572 feet.

Kleburg County, South Corpus Christi District

Baffin Bay Field.—Skelly Oil Company's State No. 1, submerged tract 385, Laguna de Los Olmos, flowed 136 bbl. of 39.3° gravity oil on July 4, to open the Baffin Bay field from perforations at 7394 to 7398 ft. in a Frio sand under 1225 lb. working pressure. Total depth of this well is 9428 feet.

Nueces County, South Corpus Christi District

East Flour Bluff Field.—Humble Oil and Refining Company's State No. 1-D, tract 30, in Laguna Madre, one mile east of Flour Bluff production and on the downthrow side of this field's main fault, was completed on May 17. The flow was 177 bbl. of 41° gravity oil from perforations at 6790 to 6800 ft. in Marginulina sand at 6780 to 6800 ft. Production was through ⅛-in. choke under 1725 lb. working pressure. The gas-oil ratio is 1962:1.

Shield Field.—Shield field was opened on July 31 by Frank W. Shield's Moore No. 1, survey 143, three miles southwest of the Baldwin field. It was completed for a flow of 152 bbl. of 44.3° gravity from perforations at 6622 to 6626 ft., in a Frio sand at 6603 to 6657 ft. Pressures were 925 lb. on tubing and 1050 lb. on casing.

Another Frio sand was established as productive by Shield, Allen and Morris' Allen and Gallagher No. 1, survey 147, 4700 ft. north of the discovery. This well flowed 153 bbl. of 56° gravity distillate and 1,500,000 cu. ft. of gas daily from perforations at 6970 to 6974 ft. in a sand at 6945 to 6975 ft. Pressures were 2385 lb on tubing and 2525 lb. on casing.

East Agua Dulce Field.—F. A. Gillespie and Son's Dabney No. 1, sec. 80, two miles east of Agua Dulce production, flowed at the rate of approximately 96,000,000 cu. ft. of gas with 90 bbl. of 56° gravity distillate, on Dec. 14. It opened the East Agua Dulce field from perforations at 7216 to 7221 ft. in a Frio sand at 7200 to 7220 ft. Flow was through ⅛-in. choke, under 2450 lb. tubing and 2560 lb. casing pressure.

East Luby Field.—Seaboard Oil Company's J. O. Chapman Estate No. 1, sec. 78, flowed 1,500,000 cu. ft. of gas and 15 bbl. of 56° gravity distillate to open this field on Dec. 17, 2½ miles east of the Luby field. Production was from perforations at 4023 to 4027 ft. in a Miocene sand at 4023 to 4038 ft., through 3⁄16-in. choke, under 1320 lb. tubing pressure and 1370 lb. casing pressure. The total depth is 7628 feet.

New Sands in Existing Fields, Nueces County

Robston Field.—Richardson Petroleum Company's Studer No. 1, Paul's subdivision, one mile north of the Robston townsite, flowed 220 bbl. of 36.8° gravity oil daily under 300 lb. working pressure, to open a new producing level from perforations at 5195 to 5207½ ft. in a Frio sand.

Stratton Field.—Southern Mineral's Bertram No. 1, sec. 203, on the east flank of the Stratton structure, was completed on June 19 as the first crude oil producer in this field, which previously had produced distillate and gas. Production was obtained from a regular Frio sand found at 6380 to 6403 ft., through perforations at 6390 to 6398 ft. The well flowed 76 bbl. of 42° gravity oil through 3⁄32-in. choke, under 900 lb. tubing pressure and 1250 lb. casing pressure.

S. E. W. Oil Company's Union Center No. 1, also on the east flank, flowed 160 bbl. of 40° gravity oil through ⅛-in. choke,

from perforations at 6680 to 6702 ft. in a Frio sand at 6667 to 6708 ft. Pressures were 700 lb. on tubing and 1060 lb. on casing.

Baytex Oil Corporation's Union Central No. 2, sec. 197, opened another crude zone when it flowed 170 bbl. of oil from perforations at 6515 to 6532 ft. in a Frio sand. Pressures were 1325 on tubing and 925 lb. on casing.

Conroe Oil Company's Sellers No. 1, sec. 204, flowed 161 bbl. of 39° gravity oil from Frio sand at 6438 to 6460 feet.

Agua Dulce Field.—Richardson Oil Company's McCoy No. 2 flowed 187 bbl. of oil, through ⅛-in. choke, from a Frio sand at 6814 to 6820 ft., under 1375 lb. tubing pressure and 1906 lb. casing pressure.

The same company's Guaranty Title and Trust Company No. 1, 3000 ft. east of production, flowed 165 bbl. of 39.8° gravity oil daily from perforations at 6889 to 6895 ft., in one of the field's regular Frio sands, which in the main field produces distillate and gas. Flow was under 1750 lb. pressure.

South Clara Driscoll Field.—Texas Conservative Oil Company's Hattie Flynn No. 5-B flowed 119 bbl. of 40° gravity oil from perforations at 5826 to 5830 ft., in a Frio sand topped at 5816 ft. Production was through 1⁄64-in. choke under 375 lb. tubing pressure and 780 lb. casing pressure.

East White Point Field.—Sinclair-Prairie Oil Company's State Nueces Bay No. 2, submerged tract 974, was completed from perforations at 5850 to 5862 ft. in a Frio sand, for a flow of 135 bbl. of 40.4° gravity oil under 925 lb. tubing pressure. Gas-oil ratio is 1005:1 and the total depth is 6362 feet.

San Patricio County, South Corpus Christi District

New Sands in Existing Fields

East White Point Field.—Houston Oil Company completed its Baldwin No. 7, sec. 46, in a *Heterostegina* sand at 4932 to 4954 ft., for a flow of 130 bbl. of 26.8° gravity crude from perforations at 4930 to 4936 ft. The pressures were 1050 lb. on tubing and 1550 lb. on casing. The regular Frio sand, topped at 5693 ft., tested oil with salt water.

Republic Natural Gas Company's E. A. Rachal No. 38, Flores survey, found a distillate sand at 5730 to 5775 ft. in the Frio after missing the regular 5600-ft. sand, and on completion flowed 30 bbl. of 59.4° gravity distillate with gas under 850 lb. tubing pressure and 2240 lb. casing pressure.

Aransas Pass Field.—Baytex Oil Company's Peoples and Nichols No. 1, block 208, flowed 70 bbl. of 56° gravity distillate with gas from a new Frio sand, through perforations at 7454 to 7461 feet. Pressures were 2600 lb. on tubing and 2800 lb. on casing.

Odem Field.—Sharp and Wood's Hart No. 1, one mile northwest of Odem, Burgess survey, produced 71 bbl. of 36.1° gravity oil through ½-in. choke under 175 lb. working pressure, to open the first crude production for this formerly distillate-producing area. Production was obtained from perforations at 6901 to 6921 ft. in a Frio sand found at 6901 to 6936 feet.

East Mathis Field.—Seaboard Oil Company's Lovett No. 1, sec. 13, midway between the field's two producers, was completed from perforations at 5614 to 5618 ft. in a Jackson (?) sand at 5599 to 5627 ft. for a flow of 140 bbl. of 41° gravity oil through ⅛-in. choke. Pressures were 1000 lb. tubing and 1350 lb. on casing. At the year's end the oil-gas ratio was 18,900:1.

Willacy County, South Corpus Christi District

Willamar Field.—Pan-American Production Company's Willamar Community No. 1, San Juan de Carricios grant, 6 miles southeast of Willamar, flowed 263 bbl. of 29.8° gravity Mirando type crude through ¼-in. choke, under 350 lb. tubing pressure,

casing sealed. It opened the Willamar field on Nov. 14. Production was obtained from Frio sands at 7620 to 7710 ft. through a series of perforations at 7620 to 7634 ft., 7644 to 7660 ft., 7668 to 7678 ft., with a total of 70 shots. Gas-oil ratio was 200:1. The total depth is 9003 ft. This is the first crude producer so far downdip in the Rio Grande Valley. The closest producers are the distillate and gas wells of southeastern Hidalgo County.

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West Texas Oil Development in 1940

By P. P. Gregory,* Member A.I.M.E.

The rate of drilling operations in the West Texas district during 1940 was approximately equal to that of 1939. The total number of wells drilled in the area during the year was 1834, of which 1716 were completed as oil producers, 12 were gas wells and 106 were dry holes. The number of wildcat wells drilled during the year was comparatively small. The drilling of inside locations in proven areas and the drilling of wells for the purpose of extending the productive limits in producing fields constituted the bulk of development during 1940. Gaines County led all other counties in the district in the total number of oil-well completions.

The oil production totaled 83,345,381 bbl., the highest figure for any year since proration was begun. The 1940 oil production exceeded the 1939 production by approximately four million barrels.

Discoveries

While comparatively few new oil-producing areas were discovered during 1940, it appears that the oil production found in Simpson lime in the Abell field, Pecos County, was an outstanding discovery for the year. This was the second Ordovician discovery in Pecos County. Taubert, McKee & Siemoneit located its discovery well, V. W. Crockett No. 1, sec. 4½, H. & T. C. R.R. Co. survey in the Imperial area of northwestern Pecos County. The top of pay was encountered at 5270 ft., and the well was bottomed at 5357 ft. in Simpson lime, on Oct. 17, 1940. The initial production was 928 bbl. of 43° gravity sweet oil in 11 hr. 23 min., flowing naturally through 2-in. tubing with gas-oil ratio of 783 cu. ft. per barrel. Following the completion of the discovery well, large blocks of land were leased in the area, and several locations were made toward the close of the year. There is every indication that the Abell field will become a major producing field in the West Texas district. There was no pipe-line outlet for the field at the end of the year.

Shipley-Silurian field, discovered by the Gulf Oil Corporation, appears to be another major addition to the oil reserves in 1940. The discovery well, Wristen Brothers No. 5, is in sec. 18, block 5, H. & T. C. R.R. Co. survey in Ward County. The well was drilled to a total depth of 9187 ft. and was plugged back to 7075 ft. The Silurian lime section was acidized with 3000 gal., from 6993 to 7075 ft., and on Dec. 5, 1940, the well was completed for initial production of 3040 bbl. of 32.2° gravity oil in 24 hr., flowing through tubing.

Todd Deep field, Crockett County, was discovered by the Continental Oil Co. et al. The discovery well, J. S. Todd No. 2, sec. 29, block WX, G.C. & S.F. R.R. Co. survey, was completed on April 3, 1940. The top of pay was encountered at 5623 ft., and the well was bottomed at 5691 ft. for initial production of 1613 bbl. of 40.6° gravity oil flowing naturally through 2-in. tubing. The pay section was found in Strawn lime of Pennsylvanian age. There were six producing wells in the field at the end of the year. This appears to be another major discovery in 1940. There was no pipe-line outlet in the field at the end of the

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* Chairman, Yates Pool Engineering Committee, Iraan, Texas.

TABLE 1.—*Oil and Gas Production in West Texas*

Line Number	*County*, Field	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
1	*Andrews:* Deep Rock (Walker-Fuhrman)	1931	4,370	0	3,188,437	557,943
2	Emma	1937	1,100	0	572,919	247,938
3	Means	1934	8,000	0	4,039,230	836,605
4	Parker	1934	160	0	69,186	10,863
5	West Andrews	1940	y	0	4,553	4,553
6	*Cochran:* Dean	1937	360	160	62,127	18,710
7	*Crane-Upton:* Church Fields-McElroy-McClintic	1926	14,000	0	117,742,202	5,049,744
8	*Crane:* Dune	1938	2,200	0	280,831	127,038
9	Sand Hills (Permian)	1930	5,420	0	2,208 521	656,092
10	Sand Hills (Ordovician)	1936	1,000	0	372,315	123,302
11	*Crockett:* Crockett	1938	1,020	0	193,637	97,603
12	Noelke	1940	y	0	13,058	13,058
13	Todd Deep	1940	y	0	28,541	28,541
14	World-Powell	1926	2,240	0	7,026,698	411,156
15	*Ector:* South Cowden-Foster-Johnson	1933	17,390	0	10,755,329	4,045,898
16	Goldsmith	1934	29,500	y	24,558,169	7,980,280
17	Harper	1933	4,500	0	6,311,180	1,249,456
18	North Cowden	1930	18,600	0	16,029,780	3,567,034
19	North Cowden (Deep)	1939	200	0	48,627	36,211
20	*Ector-Crane:* Penwell-Jordan-Waddel	1927	17,000	1,000	27,135,406	3,067,742
21	*Gaines:* Cedar Lake	1939	5,000[1]	0	53,182	47,281
22	Seminole	1937	11,000[1]	0	1,313,869	981,971
23	Wasson (Deep)	1940	y	0	1,849	1,849
24	*Gaines-Yoakum:* Wasson	1936	58,000	0	20,037,919	10,978,593
25	*Garza:* Garza (Emerald)	1925	320	0	97,559	3,401
26	*Glasscock-Howard:* Chalk-Roberts	1926	21,700	0	95,291,353	4,984,291
27	1400-foot pay	1927	1,700	0	[2]	[2]
28	1800-foot pay	1926	4,000	0	[2]	[2]
29	2200-foot pay	1929	8,000	0	[2]	[2]
30	2500-foot pay	1928	2,000	0	[2]	[2]
31	3000-foot pay	1928	6,000	0	[2]	[2]
32	*Hockley-Cochran:* Slaughter	1937	50,000[1]	0	2,110,194	1,157,548
33	*Howard:* Iatan-Denman	1925	6,600	0	13,557,539	1,715,631
34	Moore	1938	640	0	56,060	17,576
35	Snyder	1937	1,000	0	1,690,668	495,129
36	*Irion:* Irion	1929	340	0	149,042	5,009
37	*Loving:* Mason	1936	350	0	380,043	79,558
38	Wheat	1925	4,060	0	8,176,374	394,064
39	*Mitchell:* Westbrook	1921	4,060	0	10,791,133	260,554
40	*Pecos:* Abell	1940	y	y	5,650	5,650
41	Apco	1939	1,200	0	64,927	42,043
42	Fromme	1939	290	80	37,308	28,215
43	Grassroots	y	40	0	x	470
44	Lehn	1939	1,200	0	156,076	132,504
45	Masterson	1927	1,000[1]	0	861,105	65,501
46	Netterville	1934	1,600	0	338,460	40,562
47	Pecos Valley	1928	4,000[1]	0	2,027,490	478,397
48	Richards (Prior)	1929	160	0	29,367	643
49	Shearer	1938	320	0	824,386	288,653
50	Taylor Link (sand)	1929	450	0	556,641[1]	22,760[1]
51	Taylor Link (lime)	1929	1,900	0	5,803,356[1]	604,323[1]
52	Toborg	1928	1,314	0	6,430,153	583,231
53	Walker	1940	y	y	11,987	11,987
54	White and Baker	1935	640	640	101,632	59,470
55	Yates (sand)	1933	700	0	422,514	38,140
56	Yates (lime)	1926	20,000	0	254,265,683	6,861,864
57	*Pecos-Ward:* Payton	1937	1,770	0	2,065,165	687,446
58	*Reagan:* Big Lake (2400-ft.)	1923	275	0	[3]	[3]
59	Big Lake (3000-ft.)	1923	3,000	0	[3]	[3]
60	Big Lake Ordovician	1928	1,300	0	96,256,761	2,147,522
61	Grayson	1928	640	0	631,719	30,071
62	*Reeves:* Anthony	1939	y	y	2,111	674

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Estimated.
[2] Production of various "pays" included in field total.
[3] Production included under Big Lake Ordovician.

TABLE 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]
				During 1940		End of 1940			Number of Wells				
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[e]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	
1	*y*	1,175	64	0	0	0	64	0	45	19	1,800	*y*	
2	*x*	*x*	36	9	0	0	36	0	17	19	*x*	*y*	
3	5,220	1,092	119	19	1	0	118	1	76	42	1,900	1,550	
4	*x*	*x*	2	0	0	0	2	0	2	0	*x*	*x*	
5	*x*	*x*	3	3	0	0	3	0	0	3	*x*	*x*	
6	52	12	3	0	0	0	2	1	1	1	*y*	*y*	
7	*y*	*y*	559	43	0	0	533	0	218	315	750	*y*	
8	*x*	*x*	25	4	0	0	20	0	8	12	740	*y*	
9	2,019	670	87	22	0	0	86	0	83	3	2,125	*y*	
10	*y*	*y*	9	2	0	0	9	0	6	3	2,760	*y*	
11	*x*	*x*	27	0	0	0	27	0	4	23	*x*	*x*	
12	*x*	*x*	8	8	0	6	2	0	2	0	*x*	*x*	
13	*y*	*y*	6	6	0	0	6	0	6	0	*y*	*y*	
14	*x*	*x*	71	7	0	0	50	0	0	50	*x*	*x*	
15	*x*	2,469	641	225	0	0	637	0	399	238	1,600	1,231	
16	53,497	13,144	913	153	1	0	905	8	860	45	1,675[1]	1,397	
17	*x*	*y*	183	0	1	0	182	0	38	144	*x*	*y*	
18	53,525	9,160	415	101	0	0	411	0	385	26	1,740	1,330	
19	*x*	*x*	5	2	0	0	5	0	4	1	1,300	*y*	
20	*y*	*y*	436	76	0	0	433	3	324	109	1,525	*y*	
21	12.7	11.3	11	8	0	0	11	0	9	2	1,876	*y*	
22	1,533[1]	858[1]	164	139	0	0	164	0	164	0	2,050	1,968	
23	*x*	*x*	1	1	0	0	1	0	1	0	*y*	*y*	
24	22,356[1]	11,673[1]	1,049	436	1	0	1,048	0	1,021	27	1,800[1]	1,667	
25	*x*	*x*	8	0	0	0	5	0	0	5	*x*	*x*	
26	*x*	*x*	*y*	11	3	7	853	0	0	853	*x*	*x*	
27	*x*	*x*	107	2	0	0	107	0	0	107	*x*	*x*	
28	*x*	*x*	268	0	1	7	210	0	0	210	*x*	*x*	
29	*x*	*x*	125	0	0	0	105	0	0	105	*x*	*x*	
30	*x*	*x*	283	0	0	0	235	0	0	235	*x*	*x*	
31	*x*	*x*	212	9	2	0	196	0	0	196	*x*	*x*	
32	1,443.6[1]	779[1]	135	73	0	0	135	0	123	12	1,725[1]	1,581	
33	*x*	*x*	277	12	1	1	274	0	3	271	*x*	*x*	
34	*x*	*x*	6	0	0	0	6	0	0	6	*x*	*x*	
35	*x*	*x*	95	5	0	0	91	0	0	91	*x*	*y*	
36	*x*	*x*	17	0	0	0	9	0	0	9	*x*	*x*	
37	*x*	*x*	10	0	0	0	10	0	6	4	*x*	*y*	
38	*x*	*x*	90	5	0	1	88	0	54	34	1,650	*y*	
39	*x*	*y*	139	3	3	*y*	94	0	0	94	1,000[1]	*x*	
40	*x*	*x*	1	1	0	0	1	0	1	0	*y*	*y*	
41	49	30.3	7	4	0	0	7	0	7	0	*y*	*y*	
42	*x*	*x*	10	4	0	0	10	0	7	3	*x*	*x*	
43	*x*	*x*	2	0	0	0	2	0	0	2	*x*	*x*	
44	*x*	*x*	35	22	0	0	35	0	34	1	*x*	*y*	
45	*x*	*x*	40	0	0	0	22	0	0	22	*x*	*x*	
46	*x*	*x*	23	0	0	0	21	0	15	6	*x*	*x*	
47	*x*	*x*	188	22	*y*	0	180	0	82	98	*y*	*y*	
48	*x*	*x*	3	0	0	2	0	0	0	0	*x*	*x*	
49	*x*	*x*	42	4	0	0	42	0	30	12	*x*	*x*	
50	*x*	*x*	23	0	0	0	9	0	0	9	*x*	*x*	
51	*x*	*x*	88	5	0	0	87	0	0	87	*x*	*x*	
52	*x*	11[1]	233	18	4	0	229	0	0	229	*x*	*x*	
53	*x*	*x*	5	5	0	0	5	0	5	0	*x*	*x*	
54	*x*	*y*	12	4	0	0	12	0	12	0	900[1]	*y*	
55	*x*	*x*	10	0	0	0	10	0	0	10	100	*x*	
56	117,981.6	1,422	558	2	0	4	554	0	529	29	700	530	
57	*y*	*y*	142	5	1	0	141	0	91	50	750[1]	*y*	RP
58	*x*	*x*	21	0	0	2	3	0	0	3	*x*	*x*	
59	*x*	*x*	261	0	1	2	183	0	0	183	*x*	*x*	
60	*x*	*y*	24	0	0	2	12	3	4	8	3,600	*y*	
61	*x*	*x*	5	0	0	0	5	0	0	5	*x*	*x*	
62	*x*	*x*	1	0	0	0	1	0	1	0	*x*	*x*	

TABLE 1.—(*Continued*)

Line Number	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Producing Formation: Age[e]	Producing Formation: Character[f]	Producing Formation: Porosity[g]	Producing Formation: Depth, Avg. Ft.: Top Prod. Zone	Producing Formation: Depth, Avg. Ft.: Bottoms Prod. Wells	Producing Formation: Net Thickness, Avg. Ft.	Producing Formation: Structure[h]	Deepest Zone Tested to End of 1940: Name	Deepest Zone Tested to End of 1940: Depth of Hole, Ft.
1	28	y	Big Lime	Per	D	Por	4,350	4,625	25	A	Per	5,088
2	34.6	y	Big Lime	Per	D	Por	4,190	4,225	25	A	Per	4,350
3	29	y	Big Lime	Per	DL	Por	4,475	4,535	25	A	Per	5,227
4	29.5	y	Big Lime	Per	D	Por	4,627	4,790	5	MC	Per	4,814
5	y	y	San Andres	Per	D	Por	4,300	4,400	y	A	Per	y
6	30	x	Big Lime	Per	DL	Por	4,900	5,010	y	y	Per	5,076
7	32	2.4	Big Lime	Per	DL	15	2,800	3,000	75	A	Ord	12,786
8	36	y	Big Lime	Per	DL	Por	3,150	3,270	40	A	Per	3,503
9	35	y	Big Lime	Per	DL	Por	4,250	4,450	50	A	Pre-Cambrian	7,158
10	44.7	0	Simpson Ellenberger	Ord	DS	Cav	5,900	6,000	20	AF	Pre-Cambrian	7,158
11	31	y	Grayburg	Per	DS	Por	1,330	1,450	12	A	San Andres	1,635
12	y	y	Yates sand	Per	S	Por	y	y	10[1]	y	Per	y
13	41.6	0	Strawn Lime	Pen	L	Por	5,727	5,807	y	y	Pen	5,914
14	29	y	Big Lime	Per	DL	Por	2,450	2,550	13	A	Per	3,695
15	34	y	Big Lime	Per	DS	Por	4,000	4,350	20	A	Per	4,627
16	36	1.9	Big Lime	Per	DL	Por	4,180	4,250	70	A	Per	6,090
17	34.8	y	Big Lime	Per	DL	Por	4,000	4,200	20	MC	San Andres	4,518
18	34	y	Big Lime	Per	DS	Por	4,000	4,350	40[1]	A	Clear Fork	5,200
19	34	1	Holt	Per	DL	Por	5,100	5,150	5	A	Per	5,200
20	33	2.1	Judkins pay	Per	DL	Por	3,450	3,600	50	A	Per	4,002
21	33	2.1	Big Lime	Per	LS	Por	4,650	4,760	70	A	Per	4,830
22	37.5	y	Big Lime	Per	DL	Por	5,050	5,300	y	A	Per	5,358
23	y	y	Big Lime	Per	DL	Por	6,210	6,881	y	y	Per	y
24	34	1.8	Big Lime	Per	DL	Por	5,050	5,300	y	A	Per	6,881
25	39	y	Big Lime	Per	SL	Por	2,000	2,510	10	A	Per	4,801
26	y	y	Data: Producing formation and deepest zone tested included separately									
27	32	1.0	Yates sand	Per	S	Por	1,280	1,400	20	A	Ord	10,906
28	32	0.8	1800-foot pay	Per	S	20	1,650	1,900	20	A	Ord	10,906
29	30	1.6	2200-foot pay	Per	DL	Por	2,150	2,300	30	A	Ord	10,906
30	30	y	2500-foot pay	Per	DL	Por	2,400	2,500	30	A	Ord	10,906
31	27	3.4	3000-foot pay	Per	DL	Por	2,900	3,000	20	A	Ord	10,906
32	32	1.9	Big Lime	Per	DL	Por	4,950	5,030	y	MC	Per	5,521
33	27	y	Big Lime	Per	DL	Por	2,450	2,800	50	A	Per	4,220
34	y	y	Big Lime	Per	DL	Por	3,200	3,200	3	y	Per	3,205
35	30.1	y	Big Lime	Per	DL	Por	2,650	2,825	y	A	Per	3,205
36	38	0	Yates sand	Per	S	Por	1,400	1,410	10	M	Per	3,972
37	39	y	Delaware sand	Per	S	Por	3,931	3,953	10	T	Per	4,165
38	38	y	Delaware sand	Per	S	Por	4,290	4,310	7	MC	Per	4,083
39	23	y	Big Lime	Per	DL	Por	2,800	3,000	50	MC	Per	5,250
40	43	0	Simpson	Ord	DL	Por	5,270	5,356	y	y	Ord	5,356
41	41	0	Ellenberger	Ord	DL	Por	4,550	4,580	30	A	Ellenberger	4,782
42	27	x	Shipley sand	Per	S-DL	18	1,412	1,443	31	D	Per	1,674
43	17	0	x	y	y	Por	50	60	y	x	y	y
44	y	y	Big Lime	Per	DS	Por	1,675	1,700	y	y	y	
45	28	y	Pecos Valley sand	Per	S	Por	1,200	1,400	5	M	Per	1,675
46	y	y	Yates sand	Per	S	Por	2,200	2,300	15	A	Per	2,459
47	31	y	Yates sand	Per	S	Por	1,300	1,600	15	A	Per	2,550
48	24	0	Yates sand	Per	S	Por	1,385	1,400	15	A	Per	4,375
49	35	y	Pecos Valley sand	Per	S	Por	1,415	1,465	y	y	Ord	4,595
50	31	y	Yates sand	Per	S	Por	970	1,016	30	A	Per	2,185
51	29	y	Big Lime	Per	DL	Por	1,630	1,675	15	A	Per	2,185
52	19	2.1	Toborg	Cre	S	Por	400	445	20[1]	AL	Per	1,400
53	y	y	Big Lime	Per	DS	Por	y	y	y	y	Ord	9,811
54	y	y	Big Lime	Per	DS	Por	1,650	1,700	10	A	Ord	9,811
55	32	0	Yates sand	Per	S	Por	900	1,100	15	AL	Per	1,852
56	30	y	Big Lime	Per	DL	Cav	1,310	1,450	100[1]	A	Per	1,938
57	33.5	y	Yates sand	Per	S	Por	2,000	2,080	80	A	Shipley Ls	3,200
58	35	y	Big Lime	Per	S	Por	2,375	2,500	40	A	Lower Ord	9,562
59	36	y	Big Lake Ls	Per	DL	Por	2,960	3,000	60	AD	Lower Ord	9,562
60	44	y	Ellenberger Ls	Ord	DL	Por	8,200	8,900	x	D	Lower Ord	9,562
61	32	y	Big Lime	Per	DL	Por	3,050	3,100	y	D	Mis	9,967
62	30	y	y	y	y	y	y	1,680	y	y	y	y

year, and the oil was being trucked to a pipe-line outlet near Ozona, Texas.

Noelke field was discovered by Soma Oil and Gas Syndicate, the field being some 5 miles southeast of the Yates pool. The discovery well, W. T. Noelke No. 1, is in sec. 30, block GG, H.E. & W.T. survey in Crockett County. The oil production was found in a sand member of Yates section above the top of brown lime. While several fairly large wells were completed in the Noelke field, there was no pipe line outlet for the field, and at the end of the year little information was available on the area.

Live Oak field was discovered by Moore Exploration Co., in Crockett County, when its discovery well, A. C. Hoover No. 1, encountered production in Permian lime from 1984 to 2150 ft. The initial production was approximately 53 bbl. of oil in 24 hr. pumping through 2-in. tubing. The same company discovered Permian production in the Olson field when it completed its Noelke Livestock Co. well No. 1 for 130 bbl. of oil in 24 hr. pumping. The well is in sec. 10, block GG, T. & N.O. R.R. Co. survey, Crockett County. Rapid decline in production observed in the wells of the two areas indicates that they can be of only minor importance. The West Andrews field was another minor oil-producing area, discovered by the Atlantic Refining Co. The discovery well, University No. 1, sec. 11, block 11, University Lands, Andrews County, was completed at total depth of 4,475 ft. in Permian lime on July 7, 1940. Top of pay was found at 4350 ft., and the well was completed for 168 bbl. of oil and 9 bbl. of sulphur water on a 24-hr. pumping test through tubing.

TABLE 1.—(*Continued*)

Line Number	*County*, Field	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1940	During 1940
63	*Schleicher:* Opp	1939	*y*	*y*	2,595	730
64	Page	1939	*y*	*y*	22,881	12,520
65	*Scurry-Mitchell:* Sharon Ridge[4]	1924	*y*	0	478,367	279,719
66	*Upton Crane:* { McCamey-Hurdle-Herrington-Crane Cowden	1925	20,000	0	54,001,831	4,342,151
67	*Upton:* Webb-Ray (Cordova Union)	1936	160	0	50,240	8,785
68	*Ward:* Dobbs	1937	40	0	17,412	2,099
69	Estes	1936	4,500	2,000	10,583,197	2,463,394
70	Magnolia Sealey	1938	1,000[1]	*y*	458,058	238,352
71	Magnolia Sealey (South)	1940	120	0	6,757	6,757
72	Monroe	1930	80[1]	0	48,021	6,206
73	North Ward	1929	10,000	*y*	21,669,869	2,147,351
74	South Ward	1930	11,800	*y*	26,250,947	1,717,704
75	Shipley	1928	2,500	0	3,160,384	485,526
76	*Winkler:* Eaves	1936	320	0	382,320	122,449
77	Emperor	1936	2,000	360	2,297,176	527,990
78	Halley	1935	820	10	742,644	101,527
79	Henderson	1935	2,800[1]	0	4,429,043	980,413
80	Hendrick	1927	12,138	0	202,530,944	2,952,753
81	Kermit	1928	15,240	*y*	26,467,731	3,179,647
82	Keystone (Colby sand)	1935	7,000	*y*	1,803,252	982,216
83	Keystone (lime)	1935	9,500	0	3,831,511	667,399
84	Leck	1927	960	*y*	3,721,297	165,075
85	Scarbrough	1927	3,790	0	4,943,798	546,542
86	*Yoakum:* Waples-Platter	1939	*y*	*y*	24,320	15,076
87	West Pool (Bohago Bond)	1938	40	0	25,683	10,652

[4] Formerly Ira-Northwest.

The oil production was observed to be declining rapidly in that well.

Major Extensions of Producing Fields

The most active area during 1940 was the Wasson field, of Gaines and Yoakum Counties, which accounted for 436 completions. This additional drilling extended the productive area of the field, and at the end of the year the field embraced approximately 58,000 acres. The Seminole field, Gaines County, after securing a pipe-line outlet, saw a revival of drilling activity during the year. One hundred and thirty-nine oil wells were drilled during 1940, and the productive area of the field was extended by some 6000 acres. The Slaughter field, Hockley County, was extended into Cochran County to the west and into Terry County to the south. During the year, 135 oil wells were drilled in the field and indications are that the productive area will be around 50,000 acres. Additional extensions in the productive areas of Goldsmith, Sand Hills Ordovician, North Cowden and Cedar Lake were also made.

Acknowledgments

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Table 1.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940		Reservoir Pressure, Lb. per Sq. In.		Repressuring Operation[d]
				During 1940		End of 1940			Number of Wells				
	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[e]	Producing Gas[c]	Flowing	Artificial Lift	Initial	Avg. at End of 1940	
63	x	x	1	0	0	1	0	0	0	0	x	x	
64	y	y	5	1	0	4	1	0	1	0	y	y	
65	x	x	99	66	0	0	99	0	4	95	x	x	
66	x	x	1,043	9	43	0	990	0	2	988	x	x	
67	x	x	5	0	0	0	4	0	0	4	y	y	
68	x	x	2	0	0	0	1	0	0	1	x	x	
69	x	y	343	23	0	0	340	3	295	45	1,370	y	
70	x	y	55	17	0	0	55	0	33	22	x	y	
71	x	x	3	3	0	0	3	0	3	0	x	y	
72	x	x	2	0	0	0	1	0	1	0	x	x	
73	x	x	412	43	0	0	410	2	y	y	1,400	x	
74	x	x	y	2	7	20[1]	619[1]	4	y	y	1,370	x	
75	x	x	116	12	0	2	114	0	10	104	x	x	
76	x	y	7	0	0	0	7	0	4	3	x	y	
77	x	x	103	11	0	0	97	6	92	5	1,300	y	
78	x	x	26	0	0	1	25	0	16	9	1,235	y	
79	x	y	139	2	0	0	139	0	137	2	1,450	y	
80	y	y	631	0	25	0	307	0	81	226	1,720	y	
81	65,656	17,900	894	7	19	0	842	20	512	330	1,450	440	SR
82	x	y	159[1]	19	0	4	152	3	134	18	1,520	y	
83	x	y	84	8	0	0	84	0	76	8	x	y	
84	x	y	17	0	0	0	9	0	1	8	x	y	
85	x	810	151	18	0	1	137	0	97	40	1,450	y	SR
86	y	y	2	1	0	0	2	0	1	1	y	y	
87	y	y	1	0	0	0	1	0	0	1	x	x	

McKinnon, Shell Oil Co., McCamey; V. E. Cottingham, North Basin Engineering Committee, Midland; E. Russell Lloyd, Midland; W. H. Gilmore, Culbertson and Irwin, Midland; Taylor Cole, University Lands, Midland.

TABLE 1.—(*Continued*)

Line Number	Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
	Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
63	34	y	y	y	y	y	y	4,081	y	y	y	y
64	41	0	Strawn	Pen	L	Por	y	y	y	y	y	y
65	25	y	Big Lime	Per	DC	Por	2,320	2,395	25	A	Per	4,528
66	28	y	Big Lime	Per	DL	Por	2,250	2,300	30	A	Per	4,610
67	25	y	Grayburg	Per	DL	Por	2,060	2,150	y	A	Per	2,176
68	37	y	Shipley-Hazlett	Per	S	Por	2,550	2,570	7	y	Per	2,600
69	34	y	Estes sand	Per	DS	Por	2,450	2,950	50	A	Per	3,000
70	32.7	y	Big Lime	Per	DL	Por	2,878	2,952	y	A	Per	3,085
71	28	y	Big Lime	Per	DL	Por	2,880	2,910	y	y	Per	3,085
72	29	y	Delaware sand	Per	S	Por	4,665	4,675	5	T	Per	4,692
73	36	1	O'Brien sand	Per	SD	Por	2,500	2,750	50	ML	Per	4,825
74	32	y	O'Brien sand	Per	S	Por	2,300	2,525	40	ML	Per	4,825
75	34	y	Shipley Ls	Per	DS	Por	2,900	3,100	50	A	Ord	9,187
76	26	y	White Horse	Per	DL	Por	3,100	3,170	40	A	Per	3,175
77	33	y	White Horse	Per	S	Por	2,833	3,100	40	AC	White Horse Ls	3,145
78	31.1	y	White Horse sand	Per	S	Por	3,100	3,200	22	AC	San Andres	3,855
79	30	y	Big Lime	Per	DL	Cav	3,025	3,075	30	A	Per	3,450
80	28	1.4	Big Lime	Per	DL	Cav	2,600	2,900	y	A	Per	3,920
81	35	y	Yates sand	Per	LS	Por	2,825	3,200	10	A	Per	3,414
82	36	y	Colby sand	Per	S	Por	3,215	3,313	98	AD	Per	3,702
83	36.5	y	Keystone Lime	Per	DL	Por	3,210	3,360	y	AD	Per	3,702
84	28	y	Big Lime	Per	DL	Por	3,000	3,100	y	A	Per	3,780
85	35	y	Yates sand	Per	LS	Por	2,800	3,050	10	A	Per	3,565
86	31	y	San Andres	Per	DL	Por	5,219	5,300	35	MC	Per	5,380
87	31	y	Big Lime	Per	DL	Por	5,168	5,255	10	MC	Per	5,255

Oil and Gas Development in West Virginia during 1940

By David B. Reger,* Member A.I.M.E.

The substantial expansion of previously discovered gas pools was the principal feature of petroleum activity in West Virginia during 1940. At least one new gas pool was discovered and various other successful wildcat completions may prove to be gas-pool openers. Some slight extensions of oil pools were also made. The new productive territory, principally gas, added by these extensions was approximately 33,800 acres.

In general, oil activity was slight because of unfavorable crude prices. Gas activity, on the contrary, increased considerably, although the price of gas did not materially change. The account of operations, as gathered from trade journals and other reporting services, shows that 709 new wells were drilled, resulting in 102 new oil wells with 1055 bbl. of daily new production; 468 new gas wells with 633,947,000 cu. ft. of daily open flow; and 139 dry holes. Also, 91 old wells were drilled to deeper sands, with 143 bbl. and 44,833,000 cu. ft. of added production. On the new wells the oil average was 10.34 bbl. per well per day; and the gas average was 1,354,000 cu. ft. per well per day. On new wells the ratio of dry holes to completions was 19.61 per cent. On deeper drilling to other sands the ratio of failures was 12.1 per cent.

From an exploratory standpoint, one strictly new gas pool (Lorentz) was opened in Upshur County. Little forecast of its extent or reserve can now be made. The new extensions of various other previously discovered pools, however, give assurance of a new gas reserve that will equal approximately a year of gas demand. In addition to these definite supplies two widely separated Oriskany sand (L. Dev.) wildcats in Jackson County, one of which was completed late in 1940 and the other early in 1941, may indicate two separate pools or may greatly extend known pools. In southern Kanawha County, also, an old Oriskany-sand well deepened to the White Clinton sand (Sil.) showed a volume of 733,000 cu. ft. and rock pressure of 1800 lb., giving rather clear assurance that this deep sand, in which only slight quantities of gas had previously been found, should eventually supply much new gas. On the other hand, various deep tests to the Oriskany sand in Harrison, Putnam, Randolph and Wood Counties were totally dry or gave only small volumes of gas.

The principal oil wells completed, by counties, were: Calhoun, 15; Clay, 11; Pleasants, 14; Ritchie, 15; and Roane, 7. Production for the year was estimated by the U. S. Bureau of Mines as 3,444,000 bbl., as compared to 3,684,000 bbl. in 1939. The leading counties in gas-well completions were: Boone, 36; Braxton, 17; Cabell, 25; Calhoun, 16; Clay, 22; Gilmer, 47; Jackson, 38; Kanawha, 77; Lincoln, 18; Putnam, 32; Ritchie, 40; and Wayne, 31. Production for the year is estimated by me as 170,000,000,000 cu. ft. as compared to 159,226,000,000 cu. ft.* in 1939.

No long pipe lines were built but various gas-line extensions and cross connections,

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* Consulting Geologist, Morgantown, W. Va.

* From U. S. Bur. Mines, M. M. S. No. 891. The Public Service Commission of W. Va. reports (Twenty-seventh Ann. Rept., 174) only 152,600,-308,000 cu. feet.

principally in the Elk-Poca pool of Jackson and Kanawha Counties, were made. At least four new gas-compressor stations were built within the state. Certain important amplifications of gas-transportation and handling facilities in adjacent states, however, should considerably increase the use of West Virginia gas. The dehydration of gas, both at the well mouth and at compressor stations, has been carried forward during the year.

The price of oil has fluctuated, but stood at $1.74 per barrel at the end of the year. The price of gas at the well mouth has remained almost stationary, at about 13¢ per M cu. ft., but the demand has improved.

General State of Industry

No exact figures relative to the amount of land under lease in the state are available, but for the past two or three years new leases have about equaled surrenders. A previous estimate of 4,500,000 acres under lease is still about the proper figure. As

Table 1.—*Production Statistics, West Virginia*

Period	Oil, Bbl.	Average Oil per Well Daily, Bbl.	Gas, Millions Cu. Ft.	Average Gas per Well per Day, Cu. Ft.
To end of 1940	413,535,000		6,667,026	
During 1939	3,684,000[a]	0.54	159,226[a]	29,941
During 1940	3,444,000[a]	0.54	170,000[b]	34,249

[a] Figures by U. S. Bureau of Mines, final for gas, subject to revision for oil.
[b] Estimated by D. B. R.

of the end of 1940, the leasing of land, both in old territory and in wildcat localities, was fairly active. The proved oil reserve has slightly declined because no appreciable amount of new territory has been opened to offset production. The proved gas reserve remains virtually stationary because discoveries in 1940 have about equaled production.

Up to the end of 1940 about 64,100 oil and gas wells had been completed. During the year, 102 oil wells and 468 gas wells were completed, and 744 wells were abandoned because of nonproductivity or exhaustion. At the end of the year about 17,630 oil wells and about 13,599 gas wells were active. Production statistics are given in Table 1.

Principal Areas of Activity

In Boone County, besides routine operations, a well on Robinson Creek, Crook district, was drilled to the Brown shale (M. Dev.), deeper than most other wells in the territory, and tested 1,300,000 cu. ft. of open flow and 500 lb. rock pressure. Such a well justifies a considerable amount of exploration to this formation. In Peytona district, two additional Oriskany-sand (L. Dev.) wells were completed and a third test was dry in this field. This Bull Creek locality now has four Oriskany wells, probably representing a southern extension of the Charleston gas field. In Sherman district two gas wells were completed north of the Cabin Creek oil pool, one being in the Salt sand (L. Pen.) and the other in the Berea sand (L. Mis.).

In Braxton County drilling continued to be active in the Villa Nova gas pool, which will be discussed under Clay County. In Birch district, also, three wildcats, 2 or 3 miles northeast of the Villa Nova pool, proved to be dry. In Holly district a wildcat located 2 miles northeast of Sutton and far removed from any production was reported as a gas well completed in January 1941 with an open flow of 500,000 cu. ft. in the Gordon Stray sand (U. Dev.).

In Cabell County the Porter Knob gas pool, mainly in Grant and McComas districts but extending into Carroll district, Lincoln County, was actively exploited. This pool was discovered many years ago, but never was pushed. In 1939 and 1940 drilling became active and there are now at least 14 wells. These wells are mostly

in the Berea sand (L. Mis.) but a few have been drilled to the Brown shale (M. Dev.) with additional production. The average open flow has been about 500,000 cu. ft. and the average rock pressure about 375 lb. About 4000 acres appear to have been proved.

The Bowen Creek gas pool, in McComas district, Cabell County and Union District, Wayne County, which may be classed as a 1939 discovery, continued to be active. In 1939 and 1940, 23 wells were drilled, all productive from the Brown shale, with an average open flow of about 165,000 cu. ft. and rock pressure of about 425 lb. The proved productive territory is at least 10,000 acres. This pool, incidentally, is adjacent to and connects with the Sarah gas pool of Cabell County, where commercial production in the Brown shale (or Childres sand, as it should be called) was first developed in the state. Northward from the Sarah pool scattered wells now indicate a huge producing area that may connect with the Rome township development of Lawrence County, Ohio.

In the Fourpole Creek gas pool of Guyandot district, Cabell County, and Ceredo district, Wayne County, some additional drilling was done, resulting in small Brown-shale wells. About 2000 acres appear to be proved.

In Calhoun County routine drilling for oil and gas continued. In the Sycamore oil pool of Sherman district seven Big Injun sand (L. Mis.) oil wells have been drilled, averaging 18 bbl. About 500 acres have been proved.

In Clay County various oil and gas pools were considerably extended. In Otter district, four oil wells have been completed in the Big Injun sand on Charleston Fork, indicating a local pool or a northward extension of the Reed Fork oil pool. In Pleasant district a progressive development of several years indicates eventual gas development in the Big Injun sand in the area bounded by Elk River, Sycamore Creek and Leatherwood Creek. The area of this probable territory, now only partly proved, is about 13,000 acres.

The Villa Nova gas pool, of Buffalo and Otter districts, Clay County, and Birch district, Braxton County, discovered in 1939, had about 35 completions in 1940, of which 18 were gas with average open flows of 2,783,000 cu. ft. and average rock pressure of about 500 lb. The largest well, in the Big Lime (L. Mis.), made 19,000,000 cu. ft. One Big Lime oil well of 75 bbl. and one Big Injun oil well of 25 bbl. were brought in. There were also 14 dry holes. A recent Big Injun gas well at the extreme south makes the total length of the pool about 6 miles. About 3500 acres may be considered as proved.

In Gilmer County additional drilling has widened the Glenville gas pool on the northwest and southeast. In Troy district a 10-bbl. wildcat oil well in the Blue Monday sand (U. Mis.) was completed on Leading Creek north of Troy. In Center district a wildcat gas well in the Big Injun sand, of unreported volume, was drilled a mile or so northwest of Cedarville.

In Harrison County, Grant district, Hope Natural Gas Co. is drilling a deep rotary-tool test on the Chestnut Ridge anticline a mile or more east of Lost Creek village. This well began about July 1, 1940, and by Feb. 5, 1941, had reached a depth of 9827 ft. Little or no gas was found in the Oriskany sand, which was the first objective and topped at 7290 ft. It is expected that the hole will be continued through the White Medina, or "White Clinton" sand (Sil.), which should not be far below the present depth. This well, besides being the first rotary-tool test in West Virginia, has reached a greater depth than any other hole in the Appalachian region.

In Jackson County there was a great deal of successful deep drilling, as will be separately discussed later.

In Kanawha County there was a moderate amount of drilling to the upper sands

and much drilling to the deep Oriskany sand, as will be discussed later. One Oriskany well (Campbell Creek Coal Co., 4-GW436, by Columbian Carbon Co.) was deepened to the White Clinton sand (Sil.) and tested 733,000 cu. ft. of open flow and 1800 lb. rock pressure. The well is in Loudon district, 2½ miles west of Malden, and has about the same position on the western slope of the Warfield anticline as a small White Clinton sand well completed 6½ miles to the southwestward in Boone County in 1939. Two other Oriskany wells, farther north in the Charleston gas field, are now being deepened to the White Clinton.

In Lewis County, Collins Settlement district, a wildcat in the Big Injun sand at Chapman village, several miles from other production, tested 50,000 cu. ft. and 700 lb. rock pressure.

In Lincoln County, Union and Jefferson districts, a considerable amount of new Brown shale gas has been developed at the southeastern edge of the Myra gas pool. Part of this comes from the deeper drilling of old wells.

In Logan County, Logan district, a Big Lime wildcat, with 800,000 cu. ft. of open flow, was completed within the Logan city corporation. Farther northeast in the same district various good wells were completed in the Ethel gas pool.

In Pleasants County, Grant district, a 40-bbl. oil well was completed in a formation logged as the Speechley sand or shale (U. Dev.). Other scattered wells at this approximate level in previous years afford some hope of new oil along the Burning Springs anticline.

In Putnam County, Curry district, the Trace Fork gas pool, discovered about November 1939, now has 26 completed gas wells, with production in the Salt (L. Pen.), Big Lime and Berea (L. Mis.) and Brown shale (M. Dev.). These wells have averaged 800,000 cu. ft. and about 500 lb. rock pressure. Only one dry hole is reported and only one well has been deepened to the Brown shale. At the end of 1940, 11 wells were drilling. Part of the wells are widely scattered, but a productive area of about 10,000 acres seems assured, with the prospect that most of the wells will eventually go down to the Brown shale. In Teays Valley district a Salt sand (L. Pen.) wildcat on Hurricane Creek, 3 miles south of Midway, tested 1,000,000 cu. ft. and 460 lb. rock pressure at depth of only 996 feet.

In Ritchie County, Clay district, the old Mole Hill oil and gas pool became active again by new drilling at the extreme head of Hughes River. Seven oil wells in the Cow Run sand (M. Pen.), at depth of about 1100 ft. and with a 11-bbl. per well average, have been drilled. One small Big Injun gas well and two dry holes are also reported. This drilling is confined to an area of about 200 acres.

In Roane County, Harper district, drilling was fairly active in the old Flat Fork oil and gas pool, where production is mainly from the Salt sand (L. Pen.). In 1940, seven oil wells averaging 12 bbl. per well and four gas wells, averaging 650,000 cu. ft. per well, and 12 dry holes were drilled. This operation occurred in an area of about 2500 acres, some of which might be classed as new discovery.

In Upshur County, Buckhannon district, the Lorentz gas pool is entirely new. The discovery well (Ruth Marple, 1-7754, by Pittsburgh & W. Va. Gas Co.), on Fink Run one mile east of Lorentz, had 243,000 cu. ft. of open flow but apparently was not shut in for a rock-pressure test, as the Benson sand (U. Dev.) from which the gas came is known to develop high pressure with danger to well equipment. As of the end of 1940, four gas wells, partly in the Gordon sand (U. Dev.) and partly in the Benson, had been completed, with an average open flow of 260,000 cu. ft. and with mostly unknown, or unreported, rock pressure. One Gordon sand well, however, tested 1035 lb. Two additional wells were

drilling. The development to date indicates a productive area of about 1000 acres without any definition of outside limits. In the Holly Grove gas pool of Meade district various new wells in the Squaw (L. Mis.) and Gordon sand (U. Dev.) were completed.

In Wayne County, Butler district, another Newburg sand (Sil.) gas well with 700,000 cu. ft. of open flow and 1280 lb. rock pressure was completed in the Patrick Creek gas pool. Another test to this sand on Garrett Creek was almost dry. In Lincoln district a Big Lime (L. Mis.) and Brown shale (M. Dev.) gas well (Copley Hrs., 1, by Huntington-Oklahoma Oil Co.), completed on Camp Creek 1½ miles south of Webb, tested 360,000 cu. ft. of open flow and 360 lb. rock pressure. Two previous wells in the same locality had production in upper sands, but the shale discovery appears to be new and may open a distinct pool for this formation. In Stonewall district, the Hany gas pool was extended northward by two Big Injun sand wells. In Union district the Wayne gas pool was very active. The initial drilling apparently occurred some years ago but the development gained momentum late in 1938 and continued briskly through 1939 and 1940. At least 32 gas wells and 4 dry holes have been drilled, and 9 wells were drilling at the end of 1940. Production is mainly from the Brown shale (M. Dev.) but there are scattered wells in the Big Injun and Berea sands (L. Mis.). The open-flow average is about 325,000 cu. ft. and the rock pressure about 450 lb. per well. In some parts of the pool the drilling is hardly enough to prove

TABLE 2.—*Important Wildcats Drilled in West Virginia during* 1940

No.	County	Magisterial District	Location		Total Depth, Ft.	Surface Formation
			Lat.	Long.		
1	Boone	Crook	4.91 mi. S. of 38° 05′	3.61 mi. W. of 81° 40′	4,294	Pen.-Kanawha
2	Braxton	Birch	4.06 mi. S. of 38° 40′	2.15 mi. W. of 80° 50′	1,898	Pen.-Allegheny
3	Braxton	Birch	0.95 mi. S. of 38° 40′	2.05 mi. W. of 80° 50′	2,784	Pen.-Conemaugh
4	Braxton	Birch	0.49 mi. S. of 38° 40′	3.51 mi. W. of 80° 50′	2,187	Pen.-Conemaugh
5	Cabell	Barboursville	5.40 mi. S. of 38° 30′	2.96 mi. W. of 82° 15′	3,064	Pen.-Conemaugh
6	Cabell	McComas	4.09 mi. S. of 38° 25′	2.35 mi. W. of 82° 10′	3,448	Pen.-Conemaugh
7	Gilmer	Center	4.62 mi. S. of 38° 55′	0.45 mi. W. of 80° 50′	1,944	Pen.-Conemaugh
8	Gilmer	Troy	3.32 mi. S. of 39° 05′	1.18 mi. W. of 80° 45′	1,652	Pen.-Monongahela
9	Jackson	Ravenswood	5.32 mi. S. of 39° 00′	2.67 mi. W. of 81° 35′	5,042	Perm.-Dunkard
10	Kanawha	Elk	1.01 mi. S. of 38° 20′	1.89 mi. W. of 81° 15′	2,321	Pen.-Kanawha
11	Lewis	Collins Settlement	2.60 mi. S. of 38° 55′	1.37 mi. W. of 80° 30′	2,627	Pen.-Conemaugh
12	Lincoln	Sheridan	5.53 mi. S. of 38° 20′	0.42 mi. W. of 82° 10′	3,077	Pen.-Allegheny
13	Logan	Logan	4.41 mi. S. of 37° 55′	4.03 mi. W. of 81° 55′	?	Pen.-Kanawha
14	Nicholas	Jefferson	2.27 mi. S. of 38° 20′	1.64 mi. W. of 81° 05′	2,735	Pen.-Kanawha
15	Putnam	Teays Valley	4.31 mi. S. of 38° 35′	4.41 mi. W. of 81° 55′	996	Pen.-Conemaugh
16	Putnam	Teays Valley	4.87 mi. S. of 38° 35′	0.99 mi. W. of 82° 00′	4,490	Perm.-Dunkard
17	Randolph	Valley Bend	3.37 mi. S. of 38° 50′	4.48 mi. W. of 79° 50′	1,660	Dev.-Portage
18	Upshur	Buckhannon	5.03 mi. S. of 39° 05′	2.20 mi. W. of 80° 15′	4,551	Pen.-Conemaugh
19	Wayne	Lincoln	3.78 mi. S. of 38° 00′	3.32 mi. W. of 82° 25′	2,671	Pen.-Kanawha
20	Wayne	Union	4.90 mi. S. of 39° 20′	2.41 mi. W. of 82° 25′	3,143	Pen.-Conemaugh
21	Wood	Steele	2.51 mi. S. of 39° 10′	3.81 mi. W. of 81° 30′	4,816	Perm.-Dunkard
22	Wood	Tygart	5.10 mi. S. of 39° 15′	3.60 mi. W. of 81° 30′		Perm.-Dunkard

continuous development, but a territory of about 11,000 acres, extending from the head of Millers Fork northwestward for about 8 miles to the valley of Twelvepole Creek and at present stopping about one mile northwest of Herbert, seems assured. An ironical aspect of this development is that the old Wayne County Poor Farm No. 1 well, which might have been the pool opener and which was drilled by local operators in 1925 or earlier with only slight amounts of gas and oil in the upper sands, was rigged up and drilled deeper to the shale in 1940 with fair production.

Summary of Exploration

Table 2 gives a summary of important wildcat or exploratory wells drilled during 1940, together with some others that have revealed unexpected deeper production in old fields.

Development in Oriskany Sand

Drilling to the deep Oriskany sand (L. Dev.) continued to be active in both Jackson and Kanawha Counties. The cumulative results of Oriskany drilling in these two counties since the first discovery are summarized in Table 3. In Jackson County 39 successful Oriskany gas wells were completed in 1940, without the occurrence of a single dry hole. This new production, amounting to 233,016,000 cu. ft. per day, was mostly found in a northward extension of the Elk-Poca pool but is not strictly confined to that area. In Grant and Ravenswood districts, the Buttermilk gas pool now has three Oriskany sand wells and one

Table 2.—(*Continued*)

No.	Deepest Horizon Tested	Drilled by	Property and Well No.	Initial Production per Day: Oil, Bbl.	Initial Production per Day: Gas, M Cu. Ft.	Tubing or Casing Pressure, Lb. per Sq. In.	Remarks
1	M. Dev.-Shale	Pond Fork Oil & Gas Co.	Pond Fork Coal Co., 17-56	0	1,300	500 (18 hr.)	Brown shale gas well
2	L. Mis.-Pocono	Z. N. Connolly	Dewey Baker, 1	0	0	0	Dry through Big Injun
3	L. Mis.-Pocono	Pittsburgh & W. Va. Gas Co.	G. B. Fisher, et al., 1-7725	0	0	0	Dry through Berea
4	L. Mis.-Pocono	Pittsburgh & W. Va. Gas Co.	G. B. Fisher et al., 2-7756	0	0	0	Dry through Big Injun
5	M. Dev.-Shale	Merritts Creek Gas Co.	Foundation Realty Co., 1-32	0	240	240 (72 hr.)	Brown shale gas well
6	M. Dev.-Shale	G. L. Meabon & Co.	Emily & Patrick Bledsoe, 3	0	164	365 (24 hr.)	Berea and shale gas well
7	L. Mis.-Pocono	Burge, Lowther & Shuman	Scott VanHorn, 1	0	50	?	Big Injun sand gas well
8	U. Mis.-Mauch Chunk	Bruce Haney	T. C. Scott, 1	10	0	0	Blue Monday oil well
9	L. Dev.-Oriskany	Columbian Carbon Co.	P. F. Riggs et al., 1	0	6,000	?	Oriskany gas well
10	L. Mis.-Pocono	E. L. Lusher	O. D. Hill, 1	0	0	0	Dry through Berea
11	L. Mis.-Pocono	Massey Oil & Gas Co.	George G. Keith, 1	0	50	700	Big Injun gas well
12	M. Dev.-Shale	One Mile Gas Co.	Sweetland Land & Mineral Co., 1	0	220	?	Brown shale gas well
13	L. Mis.-Pocono	O. B. Cunningham	John Justice, 1	0	800	?	Big Lime gas well
14	L. Mis.-Pocono	Hope Nat. Gas Co.	C. & H. Corp., 7822	0	47	?	Blue Monday gas show
15	L.-Pen.	Teavee Oil & Gas, Inc.	C. E. Hodges et al., 1-11	0	1,000	460 (72 hr.)	Salt sand gas well
16	L. Dev.-Oriskany	Teavee Oil & Gas, Inc.	Mees Hrs., 1-5	0	40	600 (86 hr.)	Oriskany gas show
17	L. Dev.-Oriskany	Cumberland & Allegheny Gas Co.	Elva Simmons, 1-303	0	0	0	Dry through Oriskany
18	U. Dev.-Chemung	Pittsburgh & W. Va. Gas Co.	Ruth Marple, 1-7754	0	243	?	Benson sand gas well
19	M. Dev.-Shale	Huntington-Oklahoma Oil Company	Copley Hrs., 1	0	360	360	Big Lime and Brown shale gas well
20	M. Dev.-Shale	Kentucky-W. Va. Gas Company	J. B. Burgess, 1-W-57	0	60	680 (72 hr.)	Brown shale gas well
21	L. Dev.-Oriskany	United Carbon Co.	J. K. Grimm et al., 1-811	0	119	1800 (72 hr.)	Oriskany gas well
22	L. Dev.-Oriskany	Glen W. Roberts	C. W. Cook, 1-33	0	0	0	Dry through Oriskany

Brown shale well and therefore may be safely classed as a pool. Its present known area is at least 1000 acres without dry-hole limitation. A new Oriskany well (P. F. Riggs et al., 1, by Columbian Carbon Co.), in Ravenswood district southeast of Odaville, is 3 miles south of the Buttermilk pool and may or may not be an extension. Another wildcat (B. B. Meadows, 1-875, by United Carbon Co.), in Ripley district 2 miles northwest of Kenna, has been reported late in January 1941 as having 455,000 cu. ft. of open flow and 1620 lb. of rock pressure in the Oriskany. This well is 7 miles northwest of the Elk-Poca pool. Viewed in the light of known pools and the various successful wildcats the gas future of Jackson County appears particularly bright.

In Kanawha County, Oriskany sand operations are now mostly routine. The proved area of the Elk-Poca pool, however, situated partly in Kanawha and partly in Jackson County, increased about 8000 acres in 1940, mostly on the west and north. New Oriskany drilled in Kanawha County included 66 gas wells, and only two tests that proved unproductive in this sand. Total new Oriskany gas was 217,836,-000 cu. ft. Various wells in both Jackson and Kanawha Counties had production in sands above the Oriskany. Such production has been eliminated from Table 3.

In other counties, outside of Jackson and Kanawha, various Oriskany sand wells have been drilled without very good results. In Boone County, Peytona district, two additional wells were completed to this sand in the Bull Creek pool in 1940, one having 450,000 and the other 959,000 cu. ft. A third well, completed early in 1941, was dry. Altogether, five Oriskany tests have been made in this locality with only three Oriskany producers. One of the others had gas in formations above and below the Oriskany. A sixth well is now drilling. In Harrison County, Grant district, the rotary test near Lost Creek has already been described as dry in the Oriskany. In Putnam County, Teays Valley district, a well on the head of Five-and-Twenty Mile Creek had 40,000 cu. ft. of gas and 600

TABLE 3.—*Oriskany Sand Wells, Jackson and Kanawha Counties, W. Va.*

County and Magisterial District	Completed before 1940				Completed in 1940				Total Number of Completed Wells	Number of Wells Drilling or Unreported Jan. 1, 1941
	Gas Wells		Dry in Oriskany	Total Number of Wells	Gas Wells		Dry in Oriskany	Total Number of Wells		
	Number of Wells	Gas, M Cu. Ft.			Number of Wells	Gas, M Cu. Ft.				
Jackson County:										
Grant	0	0	0	0	2	717	0	2	2	0
Ravenswood	3	3,269	2	5	1	6,000	0	1	6	3
Ripley	8	52,612	2	10	21	127,333	0	21	31	11
Washington	6	48,777	2	8	15	98,966	0	15	23	3
Total	17	104,658	6	23	39	233,016	0	39	62	17
Kanawha County:										
Big Sandy	0	0	1	1	0	0	0	0	1	0
Cabin Creek	0	0	3	3	0	0	0	0	3	0
Charleston	1	88	0	1	0	0	0	0	1	0
Elk	89	372,381	10	99	1	2,937	0	1	100	4
Jefferson	0	0	1	1	0	0	0	0	1	0
Loudon	8	3,788	5	13	0	0	0	0	13	0
Malden	35	73,181	5	40	0	0	0	0	40	0
Poca	203	1,961,147	1	204	63	210,686	1	64	268	24
Union	10	21,918	0	10	2	4,213	1	3	13	2
Washington	0	0	2	2	0	0	0	0	2	3
Total	346	2,432,503	28	374	66	217,836	2	68	442	33
Grand total	363	2,537,161	34	397	105	450,852	2	107	504	50

lb. rock pressure. In Randolph County, Valley Bend district, a well near Steiner had Oriskany salt water. In Wayne County, Butler district, a well on Patrick Creek gave no Oriskany gas, but was a producer in the Newburg. In Union district a well on Garrett Creek had neither Oriskany nor Newburg production. In Wood County two Oriskany tests were completed. One of these, in Steele district, northwest of Saulsbury, tested 119,000 cu. ft. in the Oriskany. The other, in Tygart district 2 miles southwest of Mineral Wells, was dry.

Operating Technology

Two principal items make up the history of technologic advance in 1940. One is the further progress in the dehydration of gas, which has now become highly important. To a large extent, dehydration is accomplished at central plants, of which five or six are now in operation. One of these, built in 1940, is a Blaw-Knox unit installed by Columbian Carbon Co. on Grapevine Creek, Poca district, Kanawha County. The same company has also built six small individual dehydration plants designed to treat the gas at the well mouth. These units have a capacity of 5,000,000 cu. ft. per day each, using diethylene glycol for the dehydrating solution and getting operating power from a small pressure drop to keep the solution in circulation. The unit is automatic, requiring inspection only at 8-hr. intervals.

The other principal item is the liquefaction of natural gas, which is desirable to permit storage at localities where winter peak loads create sudden large demand. This problem apparently has been solved by certain gas subsidiaries of Standard Oil Company of New Jersey. After a combined research and laboratory campaign a pilot plant was built in 1939, at the John J. Cornwell Compressor Station of Hope Natural Gas Co., Kanawha County, West Virginia, followed by the building of a commercial unit by The East Ohio Gas Co. at Cleveland, Ohio, in 1940. The Cleveland plant permits large quantities of gas, transported from the West Virginia fields in periods of low demand, to be liquefied and stored near the place of use. On a peak demand the liquid is quickly regasified for ordinary use. This research and final plant construction has been ably described by technicians of the companies concerned.*

Pipe Lines, Compressor Stations and Markets

Very few pipe lines of consequence were built within the state. In the Elk-Poca gas pool of Jackson and Kanawha Counties, Columbian Carbon Co. extended its lines farther afield. This company also built a 300-hp. compressor station at Aarons, Kanawha County, and a 1200-hp. unit on Grapevine Creek in the same county. Godfrey L. Cabot, Inc., laid about 54 miles of new gas lines of various sizes, one of which was an 8-in. line from Sissonville to South Charleston, Kanawha County. The same company built two compressor stations in the vicinity of Sissonville. Owens-Libbey-Owens Gas Dept. built 8½ miles of 8-in. line in Wayne County. Outside the state, Atlantic Seaboard Corporation, a subsidiary of Columbia Gas & Electric Corporation, built a 1700-hp. compressor station at Gala, Botetourt County, Virginia, making it possible to handle more gas on its Ky-W. Va.-Va.-Md.-Pa. 20-in. line. In Pennsylvania, certain other units of C. G. & E. Corporation built new lines from southwestern Pennsylvania to the vicinity of Olean, N. Y., mainly designed to afford an additional outlet for West Virginia gas to the New York State markets.

The price of oil has fluctuated. Starting at $2.34 per barrel on Jan. 1, it dropped to a low level of $1.44 on Aug. 28, but had risen to $1.74 on Dec. 17. The price of gas at the well mouth has remained almost stationary,

* J. A. Clark and R. W. Miller: Liquefaction, Storage and Regasification of Natural Gas. Amer. Gas Assn. Meeting, Atlantic City, 1940.

at about 13¢ per M cu. ft., but the demand has considerably improved.

County Summary

Table 4 shows by counties the new development in West Virginia during 1940. This information is compiled from all available sources, including the trade journals, the West Virginia Department of Mines, the West Virginia Geological Survey, the special Plat Service offered by Veleair C. Smith, Management, and from private reports.

The various reports are not in entire agreement, but Table 4 attempts to reflect a careful history of every individual well completed in the state in 1940.

According to the Department of Mines, 782 permits to drill were issued, including 60 permits to drill old wells deeper. Of these permits 675 have been reported to the Department as completed, but this Department summary includes holdover completions from 1939 permits. To a considerable degree the time lag, from date of permit to date of completion report, accounts for most of the discrepancies between the Department of Mines figures and those obtained from other sources.

Acknowledgments

The writer is glad to acknowledge helpful information through the year 1940 from the following organizations and individuals: West Virginia Department of Mines, Miss Marie Griffith; West Virginia Geological Survey, Mr. R. C. Tucker; Public Service Commission of West Virginia, Mr. H. J. Wagner; U. S. Bureau of Mines, Mr. G. R.

TABLE 4.—*Summary of New Development in West Virginia during* 1940

County	New Wells						Wells Drilled to Deeper Sands			
	Number of Wells	Oil Wells		Gas Wells		Dry Holes	Number of Wells	Production		Dry Holes
		Number of Wells	Bbl. per Day	Number of Wells	M Cu. Ft. per Day			Oil, Bbl. per Day	Gas, M Cu. Ft. per Day	
Boone	38	1	4	36	14,402	1	3	0	2,473	0
Braxton	30	4	155	17	14,443	9	0	0	0	0
Brooke	4	4	22	0	0	0	0	0	0	0
Cabell	30	2	30	25	4,970	3	2	0	321	0
Calhoun	37	15	192	16	7,188	6	2	25	95	0
Clay	47	11	106	22	43,767	14	0	0	0	0
Doddridge	0	0	0	0	0	0	1	0	113	0
Fayette	1	0	0	1	174	0	0	0	0	0
Gilmer	60	3	37	47	13,580	10	8	82	212	0
Hancock	9	6	46	0	0	3	0	0	0	0
Harrison	3	0	0	3	462	0	3	0	353	0
Jackson	41	2	12	39	233,016	0	0	0	0	0
Kanawha	80	2	24	77	224,494	1	12	0	27,055	1
Lewis	4	0	0	4	4,047	0	4	1	292	0
Lincoln	21	3	31	18	4,991	0	22	0	2,256	2
Logan	7	0	0	7	4,318	0	0	0	0	0
Marion	3	0	0	2	81	1	1	0	240	0
Marshall	7	0	0	5	511	2	1	0	450	0
Mingo	8	0	0	7	1,869	1	0	0	0	0
Monongalia	9	1	6	7	1,362	1	2	0	210	0
Nicholas	2	0	0	1	54	1	0	0	0	0
Pleasants	27	14	113	6	1,367	7	0	0	0	0
Putnam	33	0	0	32	23,743	1	0	0	0	0
Ritchie	83	15	152	40	13,766	28	13	10	604	5
Roane	29	7	81	6	3,788	16	1	25	0	0
Tyler	11	2	2	2	750	7	0	0	0	0
Upshur	13	0	0	11	4,266	2	0	0	0	0
Wayne	38	1	7	31	11,587	6	7	0	1,160	0
Wetzel	8	1	2	3	482	4	8	0	8,849	3
Wirt	16	4	19	2	350	10	1	0	150	0
Wood	10	4	14	1	119	5	0	0	0	0
State total	709	102	1,055	468	633,947	139	91	143	44,833	11

Hopkins; Godfrey L. Cabot, Inc., Mr. Charles Brewer, Jr.; Columbia Gas & Electric Corp., Mr. E. E. Roth; Columbian Carbon Co., Mr. R. B. Anderson; Hope Natural Gas Co., Mr. E. H. Tollefson; Owens-Libbey-Owens Gas Dept., Mr. R. C. Lafferty; Veleair C. Smith, Management (Plat Service), Mr. V. C. Smith; United Fuel Gas Co., Mr. A. H. McClain; West Virginia Gas Corporation, Mr. J. E. Billingsley. Mr. H. F. Johnston, assistant to the writer, has ably handled the statistics on completions, production, and many other details.

Development of Oil-field Activities in Argentina during 1940

By Mario L. Villa*

Argentina's oil production continues in its upward trend. The year 1940 closed with an important increase over 1939; that is, 1,996,371 bbl., or 10.72 per cent.

The Government oil fields (Y.P.F.) are responsible for these results, as their total output was 12,474,655 bbl., which compared with the 10,222,533 bbl. produced in 1939 represent an increase of 2,252,122 bbl., or 22.03 per cent. Fields operated by private companies yielded 8,134,882 bbl., against 8,390,633 bbl. in 1939, a decrease of 255,751 bbl. (3.04 per cent).

To the total of 20,609,538 bbl. produced in 1940 in Argentina, the Comodoro Rivadavia field contributed 14,976,222 bbl.; Plaza Huincul, 1,275,814 bbl.; the Province of Salta, 1,845,977 bbl. and the Province of Mendoza, 2,511,475 bbl.

Table 3 compares the output of companies working in Comodoro Rivadavia.

The total increase of 186,819 bbl. (1.26 per cent) registered in the Comodoro Rivadavia area is due only to an intensification of development programs in the known

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* Gerente General, Yacimientos Petroliferos Fiscales, Buenos Aires, Argentina.

Table 1.—*Oil and Gas Production in Argentina*

Line Number	Field, *Territory or Province*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.	
			Oil	Gas[b]	To End of 1939	During 1940
	Comodoro Rivadavia, *Chubut Territory*					
1	Zone A	33	11,190	990	103,885,854	4,352,504
2	Zone B	16	10,680	690	51,498,312	9,624,002
3	Zone C	24	2,930	250	17,191,325	999,776
4	Zone D	7			24,361	
	Plaza Huincul, *Neuquén Territory*					
5	Zone 1	22	220	120	1,648,993	39,649
6	Zone 2	14	1,580	370	4,089,582	943,384
7	Zone 3	16	590	250	9,567,247	292,781
8	Zone 4	6	40		44,678	
	Province of Salta					
9	Zone Tartagal	14	940		4,546,859	715,366
10	Zone San Pedro	12	370		9,715,817	836,740
11	Zone Agua Blanca	14	50		919,629	72,624
12	Zone Rio Pescado[1]	7	90		39,935	221,247
	Province of Mendoza					
13	Zone Cacheuta	9	360		352,001	56,136
14	Zone Tupungato	7	300		845,426	2,315,948
15	Zone El Sosneado	15	50		261,079	
16	Zone Ranquil-có	2			1,905	45
17	Zone Lunlunta[2]	2	50		1,209	139,336
18	Total		29,440	2,670	204,634,212	20,609,538

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] In 1940 normal exploitation was begun; this area previously was included in the Aguas Blancas zone.
[2] Comprises the wildcat zones of Lunlunta and Barrancas.

TABLE I.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.: To End of 1939	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1939	Number of Oil and/or Gas Wells: During 1940: Completed	Number of Oil and/or Gas Wells: During 1940: Abandoned	Number of Oil and/or Gas Wells: End of 1940: Temporarily Shut Down	Number of Oil and/or Gas Wells: End of 1940: Producing Oil[c]	Number of Oil and/or Gas Wells: End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average
1	163,556	7,175	2,471	89	70	294	1,716	26	18		x	{ 142 569	RP	207
2	34,392	5,419	795	145	8	77	698	34	6	1	x	{ 427 1,209	PM	242
3	10,734	712	760	25	33	178	347	23			285	x	PM	190
4			4			4		2			x			231
5	1,773	195	84			16	46	2			x	x	RP	307
6	8,033	2,138	164	16	4	30	126	3	21		1,110	620	PM	354
7	9,693	276	213		10	52	90	2				x	RP	336
8	1,624		5		1	2						x		384
9	6,882	853	164	13		39	126		19	26	783	608	PM	454
10	9,516	1,125	45			18	27		21	1	726	527	PM	445
11			6			1	4		1	1	413	384	PM	479
12		179	9	5	2	3	9		8		1,926	1,641	PM	499
13		40	43	1		2	26		1		x	x		316
14	219	569	17	4	2	5	13		13		3,329	3,153		333
15			14			14					x	x		129
16			2	4		1					x	x		135
17		11	3	2			3		3		x	4,266		292
18	246,422	18,692	4,799	304	130	736	3,231	92	111	29				

Line Number	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	Glauconítico y Chubutiano	CreU	S	28	{ 1,640 2,300	1,800 3,940 }	30	AF	Chubutiano	7,751
2	Glauconítico y Chubutiano	CreU	S	25	{ 2,690 4,920	2,690 6,400 }	36	AF	Chubutiano	6,389
3	Glauconítico y Chubutiano	CreU	S	28	1,640	2,130	13	AF	Chubutiano	3,660
4	Chubutiano	CreU	S	20	2,890	2,920	26	A	Chubutiano	6,615
5	Dogger	Jur	S	Por	1,870	1,990	39	MU	Liásico	3,011
6	Dogger	Jur	S	20–29	2,480	2,722	36	MU	Liásico	5,320
7	Dogger	Jur	S	Por	2,686	2,878	56	MU	Liásico	4,202
8	Dogger	Jur	S	18	3,346	3,367	7	MU	Liásico	5,038
9	{ Areniscas superiores Calcareo y Gondwana	Cre(?) Por }	S-LS	12–20	{ 2,139 2,783	2,214 3,093 }	33	A	Gondwana	6,035
10	Gondwana y Devónico	Per-Dev	S	Por	2,899	2,995	30	A	Devónico	3,920
11	Areniscas superiores	Cre(?)	S	12–22	4,592	4,920	40	A	Gondwana	5,182
12	Gondwana	Per			4,175	4,376	103	A	Terciario	4,864
13	{ Victor, Cacheuta y Potrerillos	Tri	S	Por	1,940	3,080	13	{ MUP AF	Serie Porfiritica	4,303
14	La Pilona y	Ter	HS	Por	{ 740 5,870	1,400 6,510	69	A	Victor	7,226
15	Victor	Tri	S		544	551	13	MI		
16	Neocomiano	Ter-CreL CreL	LS	Por	939	1,220	30	A	Serie Porfiritica	3,599
17	Potrerillos	Tri	S	Por	7,721	7,892	45	A	Potrerillos	9,479
18										

areas, as no new pool has been discovered.

Wells 1677, S-136 and N-5 drilled by Y.P.F. in this field are worth mentioning. The first, a deep-test well drilled in the old central area, reached 7715 ft. without encountering new oil accumulations below those already known. It was plugged back to 2818 ft. and put in production. The second well was drilled as a wildcat in the southern section of the new El Tordillo area, which will be kept as a reserve zone for future development. Well N-5, drilled on the Ballena hill in Colonia Las Heras, approximately 150 km. to the southwest of Comodoro Rivadavia, reached a depth of 6139 ft. without finding productive formations.

In the Bella Vista zone, 13 km. northwest of Comodoro Rivadavia, well 1692 reached 4371 ft., encountering only oil shows.

Wells 0-3 and 0-4, drilled in the San Jorge Gulf, 48 and 50 km., respectively, to the south of Comodoro Rivadavia, were nonproductive.

The Plaza Huincul district, in the Territory of Neuquén, taken as a whole shows a decrease in production amounting to 23,284 bbl. (1.79 per cent) notwithstanding the fact that the Government-operated areas increased their output by 34,702 bbl. (5.41 per cent). Table 4 compares production by companies.

Well NL-1, a wildcat drilled by Y.P.F. approximately 20 km. northwest of Plaza Huincul well No. 1, found a gas sand of good production at 3469 ft. Well NP-1, drilled also by Y.P.F., approximately 70 km. east of well No. 1, reached a depth of 4933 ft. without finding oil or gas shows.

Near Senillosa Station NS-2 well was drilled 65 km. east of the center of the Government-operated area, finding at 1935 ft. a gas sand that gave a daily output of 1.6 million cu. ft. of gas.

Oil production in the Province of Salta

TABLE 2.—*Summary of Drilling Operations in Argentina*

Important Wildcats Drilled by Yacimientos Petroliferos Fiscales in 1940

	Province or Territory	Location	Well No.	Total Depth, Ft.	Surface Formation	Deepest Horizon Tested	Initial Production per Day		Pressure, Lb. per Sq. In.		Remarks
							Oil, Bbl.	Gas, Millions Cu. Ft.	Casing	Tubing	
1	Chubut	Comodoro Rivadavia	S.136	6,061	Pliocene	Upper Cretaceous	755				
2	Chubut	Comodoro Rivadavia	1677	7,751	Oligocene	Upper Cretaceous	151				
3	Chubut	Comodoro Rivadavia	N.5	6,139	Cretaceous	Jurassic					Dry hole
4	Chubut	Comodoro Rivadavia	1692	4,371	Tertiary	Upper Cretaceous					Dry hole
5	Chubut	Comodoro Rivadavia	0.3	1,407	Tertiary	Upper Cretaceous					Dry hole
6	Chubut	Comodoro Rivadavia	0.4	2,667	Upper Cretaceous	Upper Cretaceous					Dry hole
7	Neuquen	Plaza Huincul	NL.1	3,792	Upper Cretaceous	Jurassic		2			
8	Neuquen	Plottier	NP.1	4,933	Upper Cretaceous	Jurassic					Dry hole
9	Neuquen	Senillosa	NS.2	4,131	Upper Cretaceous	Jurassic		1.6			
10	Salta	Tranquitas	T.106	3,908	Pliocene	Permian(?)					Dry hole
11	Salta	Solazuti	S.5	3,779	Pliocene	Pliocene					Dry hole
12	Jujuy	Yuto	JB.10	5,399	Upper Tertiary	Triassic					Dry hole
13	Mendoza	Lunlunta	L.4	8,394	Pliocene	Triassic	1,258		45	40	
14	Mendoza	Tupungato	T.25	6,201	Pliocene	Triassic	2,202	0.2	0	70	
15	Mendoza	Ranquil-Co	DP.1	1,486	Lower Cretaceous	Jurassic					Dry hole

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	30	23
Number of oil wells completed during 1940	227	43
Number of gas wells completed during 1940	3	4
Number of dry holes completed during 1940	14	32

(Table 5) increased by 135,430 bbl., which represents mainly the yield of the new Río Pescado area incorporated by Y.P.F. in July 1940. The other areas, operated by the Standard Oil Co., decreased their out-

TABLE 3.—*Output of Oil in Comodoro Rivadavia*

Company	1939, Bbl.	1940, Bbl.	Difference
Yac. Petr. Fiscales	8,283,496	8,469,730	+186,234
Ferrocarrilera	960,200	947,500	− 12,700
Industrial y Comercial	215,778	234,743	+ 18,965
Diadema	4,206,054	4,203,833	− 2,221
Astra	840,803	898,118	+ 57,315
Solano	283,132	222,358	− 60,774
Total	14,789,463	14,976,282	+186,819

put, which must be considered due to the normal decline of the fields.

Well T-106, drilled in the southern section of the Tranquitas area, 9 km. from well T-1, confirmed data obtained from well T-80 proving the location of the oil-water contact.

Wildcat S-5, drilled 7 km. northeast of the Río Pescado area, reached a depth of 3777 ft., finding only a gas sand between 682 and 695 feet.

In the Province of Mendoza oil production experienced an important increase resulting from the development program put into operation in the Tupungato area, which, notwithstanding the fact that it had only seven producing wells drilled in the lower horizon, totaled 2,315,947 bbl. in 1940; that is, an increase of 1,559,327 bbl. over 1939.

Well T-22, which in 1940 produced

TABLE 4.—*Comparison of Production by Companies*

Company	1939, Bbl.	1940, Bbl.	Difference
Yac. Petr. Fiscales	640,712	675,414	+34,702
Standard Oil Co.	236,026	197,437	−38,589
Cia. Astra	7,944	[a]	− 7,944
Cia. La República	414,366	402,963	−11,403
	1,299,048	1,275,814	−23,234

[a] In September 1939, Y.P.F. bought the area operated by this company.

869,769 bbl. of oil, has yielded in 15 months (since production began) 1,081,276 bbl., occupying thus a leading position among the country's good producers.

TABLE 5.—*Output of Oil in Province of Salta*

Company	1939, Bbl.	1940, Bbl.	Difference
Yac. Petr. Fiscales	490,702	818,046	+327,344
Standard Oil Co.	1,219,845	1,027,931	−121,914
	1,710,547	1,845,977	+135,430

Well DP-1, drilled in the Ranquil-Có area, 15 km. southwest of well RC-2, drilled in 1939, found only poor oil shows.

Petroleum in Bahrein Island in 1940*

During 1940, the Bahrein Island field produced a total of 7,073,919 bbl. of crude oil—an average of 19,328 bbl. per day. This is a decline of 514,635 bbl. from the 1939 production of 7,588,554 bbl. At the end of 1940, there were 70 producing wells.

* Information received through the courtesy of the Bahrein Petroleum Company, Ltd. May 20, 1941.

Search for Oil in Australia and Australian Territories in 1940

By Arthur Wade,* Member A.I.M.E.

The most important development in connection with the search for oil in Australia during 1940 was on the legislative side. Prior to 1939 legislative enactments in the various states with regard to prospecting for petroleum were such as to prohibit large-scale effort and to bar the major oil companies from operating. The preparation of the Wade Model Bill for the Commonwealth Government in 1939 and the acceptance of the Bill in principle by all States, has gone far to remove these obstacles. Amending Acts, largely based on the Model Bill, have now been passed by all States with the exception of New South Wales and Tasmania. In New South Wales an Amending Bill is being drafted, while the Government of Tasmania is preparing to introduce an Amending Bill provided there is any demand for it.

Noteworthy developments followed immediately on the passing of these Amending Acts. The Shell Company (1)† and the Superior Oil Company of California (2) took up large areas in Queensland and commenced work during 1940. Caltex acquired a big tract of country in the Kimberley district of Western Australia (3) and has made application for an area in the Territory of Papua. An Australian company, The Phoenix Oil Extraction Co., has obtained a permit to prospect over an extensive area bordering the south coast of Western Australia (4). Other developments are foreshadowed.

The Shell Company is making an intensive examination of its area in Queensland (1). Geological, geophysical and aerial surveys are in progress. Caltex has three geological parties in the field in Western Australia while Superior Oil Company of California has done some geological work in the interior of Queensland (2). None of these concerns envisages a drilling campaign in the near future. Much exploratory work is necessary.

Further work has been done by the companies that were already operating in 1939, though an important Australian company —Oil Search—has abandoned the work of prospecting in Australia. This company has subleased its holdings, at North West Cape in Western Australia (5), to Caltex on a royalty basis. The company also maintains its holdings in, and connection with, the Australasian Petroleum Company Proprietary Limited, which is a combination of Standard Oil (New Jersey), Anglo-Iranian and Oil Search. This company is operating in the territories of Papua and New Guinea.

Drilling

Victoria.—Although a good deal of drilling was done in the Lakes Entrance Tertiary Basin of Victoria (7), no appreciable production of oil was obtained. In order to test the extent and possibilities of the oil-bearing sand in this region, the Commonwealth and State Governments jointly put down six scout boreholes to depths of between 1200 and 1500 ft. The results were negative. A deeper exploratory borehole put down by the Governments at Seacombe, on

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* Chairman, Commonwealth Oil Advisory Committee, Canberra, A.C.T., Australia.

† Numbers in parentheses indicate the positions on the map of Fig. 1.

the coast, to a depth of 4004 ft., penetrated 50 ft. of bedrock without finding oil.

Two bore holes are being drilled to the west near the border of Victoria and South Australia. Both are testing Tertiary and Mesozoic formations. Portland No. 1 is down to 2300 ft. but has struck nothing of importance so far (8).

South Australia.—The second borehole is near Mt. Gambier, on the South Australian side of the border. Mt. Gambier No. 1 is down 942 ft. Drilling is suspended for lack of casing (8).

Western Australia.—The Freney Kimberley Oil Co., subsidized by both State and Commonwealth Governments, is drilling at Nerima Ridge in the Kimberley district of Western Australia (9). This borehole started in the Permian and is down 3300 ft. in carbonaceous sandstones. Strong showings of gas were encountered between 3200 and 3220 feet.

Queensland.—The Roma Blocks Oil Co., which is drilling near Roma in Central Queensland (10), and which struck a good showing of oil just above granite basement in its No. 1 Bore at a depth of 3510 ft., commenced drilling a No. 4 Bore 30 chains to the southwest of No. 1 toward the end of 1940. Drilling will commence in Cretaceous sediments and pass into Jurassic at shallow depth.

Territories of Papua and New Guinea.—No drilling is being done in the Territory of New Guinea though the Australasian Petroleum Co. continued its exploratory work.

In Papua the same company has selected a site at Kariava, on the Vailala River, for a deep test (6). Test drilling was carried out by the Commonwealth Government under the direction of Dr. Wade between 1915 and 1919 in an area in the Vailala River to the south of the location. The company expected to commence drilling before the

FIG. 1.—AREAS IN WHICH SEARCH FOR OIL IS ACTIVE IN AUSTRALIA AND NEW GUINEA.

T. of N. G. indicates Territory of New Guinea; P, Papua. Numbers show areas mentioned in text.

end of 1940, but unexpected mishaps and difficulties have delayed the transit of drilling plant to the selected site.

The Papuan Apinaipi Petroleum Company Limited is drilling at Oiapu near Cape Possession (11). The borehole penetrated Upper Tertiary formations to a depth of 2769 ft., meeting with some showings of oil and gas. It was abandoned in November 1940 and the plant moved to a new site farther to the south.

Petroleum Developments in Canada in 1940

By G. S. Hume*

(New York Meeting, February 1941)

Production of petroleum and natural gas increased in Canada in 1940 over the previous year. Alberta produced more than 97 per cent of the total Canadian production of 8,718,053 bbl. of oil, an increase for this province of nearly 12 per cent, whereas in Ontario and New Brunswick, where the production is relatively small, there was a slight decline. In Alberta the main producing field is Turner Valley, on the eastern edge of the foothills southwest of Calgary, and development continued in this field in 1940 with the completion of 36 wells, all of which obtained production. In the Red Coulee field, close to the International Boundary, near Coutts, no new wells were drilled and the seven producing wells showed a decline of 900 bbl. below the previous year. Also, in the Wainwright field of east central Alberta, four wells, yielding heavy crude oil, produced 4000 bbl. less oil than in 1939, owing possibly rather to discontinuous operation than to actual decline in potential yield. This decline was more than offset by production from a new field 40 miles northeast of Wainwright, at Borradaile, producing oil of 14° to 15° A.P.I. There was a small increase in production during 1940 from the Del Bonita field, in southern Alberta, where the production is from two wells.

The outstanding development of the year was the completion of Standard Oil Princess No. 2 well in the Steveville area, on the Plains 100 miles east of Calgary. This well was completed late in December with an initial flow[1] of 520 bbl. of 26.3° A.P.I. oil, and 12,750 M cu. ft. of gas from the upper part of the Mississippian limestone. It has opened up a new field and given further proof of the potentialities of the Southern Plains.

The production of petroleum in Canada is shown in Table 1. Since most of the yield comes from Alberta, the production is shown from the various fields in Table 2. The sale value of the petroleum produced in Canada in 1940 exceeded 11.1 million dollars, which is still somewhat less than the value of the natural gas production, shown in Table 3.

Table 1.—*Production of Petroleum in Canada*[a]

Barrels

Province	1939	1940
New Brunswick	20,101	21,161
Ontario	206,196	186,471
Alberta	7,595,000	8,493,237
Northwest Territories	17,013	17,184
Total	7,838,310	8,718,053
Value	$10,353,351	$11,113,000

[a] Bureau of Statistics, Ottawa.

Turner Valley, Alberta

Turner Valley continues to be by far the largest producing field in Canada (details are given in Table 4). The limits of the Turner Valley field are now known. On the east the oil area is bounded by the gas cap, which in turn is cut off on its east side by a major overthrust fault; on the west, it is defined by edge water at a level of 4100

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* Bureau of Geology and Topography, Canada Department of Mines and Resources, Mines and Geology Branch, Ottawa, Ont., Canada.

[1] Petroleum and Natural Gas Conservation Board, Alberta.

TABLE 2.—*Production of Petroleum in Alberta*[a]

BARRELS

Location	1939	1940
Turner Valley:		
Paleozoic limestone: oil wells	7,180,161	8,097,414
Gas wells	70,650	75,602
Natural gasoline	296,787	272,202
Shallow oil wells	8,431	7,309
Total	7,556,029	8,452,527
Red Coulee, 7 wells	13,022	12,177
Wainwright, 4 wells	11,624	7,527
Dina, 2 wells	4,017	4,746
Lloydminster, 2 wells	348	1,648
Vermilion	202	10,817
Moose Dome, 1 well	2,074	351
Del Bonita	2,688	3,444
Steveville, Anglo-Canadian well	687	New field discovered in December
Plains	3,720	
Total	7,594,411	8,493,237

[a] Petroleum and Natural Gas Conservation Board, Alberta.

TABLE 3.—*Production of Natural Gas in Canada*

THOUSANDS OF CUBIC FEET

Province	1939	1940
New Brunswick	606,249	616,041
Ontario	11,985,851	12,412,069
Manitoba	600	600
Saskatchewan	96,423	99,900
Alberta	22,703,964	22,709,975
Northwest Territories	1,000	
Total	35,394,087	35,838,585
Value	$12,538,954	$12,715,200

to 4500 ft. below sea level, and on the south by a southward plunge. At the north end the limits are not yet as precisely defined as elsewhere but there is a northward plunge comparable in some respects to the southward plunge at the south end. Structural conditions, however, are somewhat more complicated at the north end than at the south end because of faulting within the limestone itself. The most northerly well drilled 17½ miles north of the south end reached the top of the Paleozoic limestone at an elevation of 4254 ft. below sea level and because of the danger of edge water was not drilled through the lower porous zone. The well is an excellent producer. The upper porous zone of the limestone contains oil to a considerably lower level than the lower porous zone. One of the phenomenal features of Turner Valley is the height of the oil column from about 2000 to 4250 ft. below sea level; i.e., a vertical height of 2250 ft. The gas column in the productive zone extends from 2000 ft. below sea level to about 800 ft. above sea level, a combined vertical height for the gas and oil column of over 5000 ft. As now understood, the structure within the producing Mississippian limestone of Turner Valley is relatively simple, the limestone being in a westward-tilted fault block, slightly more than 4 miles wide, cut off by major faults on both the east and west sides. On the east edge, probably partly because of folding prior to faulting and partly because of drag folding resulting from faulting, the limestone is arched against the fault. This fold in the limestone is expressed on the surface by anticlinal conditions in much younger rocks. The structure in these younger strata over the width of the fault block is complicated by thrust faults and folds not present within the limestone itself.

Other Foothill Areas

Brazeau.—So far no success has attended efforts to discover new oil fields, other than Turner Valley, in the foothills of Alberta. The Home Brazeau well, 120 miles west and slightly north of Red Deer, Alberta, was at a depth of 6670 ft. at the beginning of 1940, when a change was made from a standard to a rotary rig on account of heavy gas flows. At a depth of about 8650 ft., a fault was encountered and the well passed from Fernie (Jurassic) to Blairmore (Lower Cretaceous) strata. The well was drilled to 8728 ft. and, after testing various horizons and finding large gas flows with small amounts of naphtha, was abandoned.

Grease Creek.—At Grease Creek, 45 miles northwest of Calgary, drilling was resumed

in the summer of 1940 at a depth of 7011 ft. in Lower Blairmore strata after a shutdown of several months. Drilling difficulties were encountered and the well was abandoned without making further progress. The well is thus not an adequate test of the Grease Creek structure but it is not known whether another well is contemplated.

Waite Valley.—In Waite Valley, west of the Turner Valley field, National No. 3 well encountered a fault at 7625 ft. and passed from Kootenay (Lower Cretaceous) to Belly River (Montana, Upper Cretaceous) strata, a stratigraphic break of over 4000 ft. The well was abandoned. The fault encountered is thought to be the Outwest fault, which cuts off the Paleozoic limestone on the west side of the Turner Valley fault block. On the strike of the formations, southeast of the National well, the limestone has been encountered at depths of less than 2500 ft. in the Highwood uplift.

Sheppard Creek.—South of the Pekisko area, the Sheppard Creek well, on the west side of township 16, range 2, west of 5th meridian, reached the top of the Paleozoic limestone at a depth of 5484 ft. but encountered water at 5952 ft. The well was continued to 5995 ft. and abandoned.

Pincher Creek.—In the southern foothills, near Beaver mines, west of Pincher Creek the Alliance well encountered a fault at 6013 ft in Fernie (Jurassic) shales when probably within less than 100 ft. of the Paleozoic limestone and passed into either the base of the Belly River or the top of the Alberta shales (Upper Cretaceous). The well was continued to 6723 ft. Tests were made of oil shows encountered in the Blairmore but these did not prove of commercial importance and the well was abandoned.

Moose Mountain.—In the Moose Mountain area, about 40 miles west of Calgary, Roxana well, 1¾ miles south of the west end of the Stony Indian Reserve, was abandoned at 6502 ft. after striking salt water. This well commenced in Lower Cretaceous strata and was completed in the base of the Devonian. It is probable that at least one fault occurred in the Paleozoic, causing considerable repetition of strata. To the south and east, where the Paleozoic limestone is exposed, McColl Frontenac, Moose Mountain No. 1 well, commenced drilling in November in the Banff (Lower Mississippian) shales. At the end of the year the well was drilling in Devonian below a depth of 2400 ft. Structurally this well is nearly 700 ft. higher than two wells drilled several years ago somewhat farther south in the valley of Canyon Creek. One of these wells, 1680 ft. deep, has produced some oil of 47° to 48° A.P.I. from what is considered to be a fracture zone, whereas the other, drilled to 2834 ft., contains some gas with naphtha coming from Devonian limestones. The

TABLE 4.—*Oil and Gas Production in Turner Valley,*[1] *Province of Alberta, Canada*

Line Number	Field, *County*	Year of Discovery	Area Proved (Drilled), Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells					
			Oil	Gas	To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	At end of 1940: Temporary Shut Down	At end of 1940: Producing Oil	At end of 1940: Capable of Producing Gas
1	Turner Valley, *Alberta*........	1924	5,000	10,000	35,931,370	8,452,527	6,121,540	47,900	252	36	1	0	131	101

[1] Information from Petroleum and Natural Gas Conservation Board, Alberta.

prospects of Moose Mountain are considered to be dependent on the presence of adequate reservoir conditions in the Devonian and the extent to which the Paleozoic without any cover of Mesozoic strata may be able to retain the gas and oil originally formed in it.

Plains Areas

Steveville.—The completion of Standard of B.C. Princess No. 2 well on sec. 13, T. 20, R. 12, west of 4th meridian in the Steveville area, about 100 miles east of Calgary, has opened up a new oil field. Previous development in this area included the drilling of several wells, of which two belonging to Anglo-Canadian Oil Co. had obtained substantial flows of gas with some oil and water in one well. Standard Princess No. 1 well completed in 1940 reached the pre-Cambrian rocks underlying the sedimentary formations of the Plains at a depth of 6147 ft. and drilling was stopped at 6155 ft. At a depth of 5258 ft. this well blew out with a very large gas flow.* On completion to the pre-Cambrian a number of porous zones were tested for oil and gas and considerable oil with water occurred in the upper part of the Devonian between 3960 and 4120 ft. Higher zones yielded no production. Encouraged by the results of this well, Princess No. 2 well was commenced in September and drilled to a depth of 4250 ft. The top of the Mississippian occurred at a depth of 3215 ft. and the top of the Devonian at about 3615 ft. The well was plugged back to 3290 ft. and showed a production rate of 380 bbl. in an 8-hr. test. After being acidized with 1000 gal., the production rate increased to 520 bbl. of 26.3° A.P.I. oil and 12,750 M cu. ft. of gas. No outcrops occur in the immediate vicinity of the well, which is on flat Prairie land, and the local structure was determined by geophysical methods. The regional geology leading to present developments was done by J. S. Irwin, Calgary.

Blood Indian Reserve near Lethbridge.—At the end of 1940 a well located by seismic survey was drilling on the Blood Reserve near Lethbridge. It is on the northwest continuation of the fold through the Del Bonita and Spring Coulee structures on the north-plunging Sweet Grass arch. Some oil is being produced from two wells on the Del Bonita structure and oil shows have occurred in the top of the Mississippian as well as in Lower Cretaceous beds in the Spring Coulee structure.

* R. E. Allen, Chairman Petroleum and Natura Gas Conservation Board, Alberta, statement Jan. 18, 1941.

Table 4.—(*Continued*)

Line Number	Oil Production Methods at End of 1940: Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial Gas Area	At End of 1940	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Producing Formation: Name	Age	Character	Porosity	Top of Prod. Zone	Bottom Prod. Wells	Net Thickness, Avg. Feet	Structure	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Feet
1	130	1	2,000+	[2]	43	Rundle (Madison)	Mis.	L	Por[3]	7,120	7,610	470[4]	A[5]	Mis	5,870[6]

[2] Not uniform in all parts of the field.
[3] 120 to 150 ft. thick.
[4] Top of Mississippian to "Black Lime" at base of lower porous zone.
[5] Tilted fault block, folded into anticline on eastern edge.
[6] Faulted at depth of 2140 ft. in Mississippian limestone.

Wainwright and Ribstone Areas, East Central Alberta.—No new wells have been drilled in either of these areas but the Montreal Alberta well at Wainwright was deepened in 1940 to 4647 ft., which is 2326 ft. into the Paleozoic. The age of the beds in the bottom of the well is not known but may be older than Devonian. Production so far obtained in the Wainwright and Ribstone areas is heavy crude oil from sands 150 to 170 ft. below the top of the Lower Cretaceous.

Borradaile Field, Vermilion Area.—In 1935 the Geological Survey of Canada outlined the Battleview anticline on Battle River, northeast of Wainwright. Subsequently this structure was covered by a seismic survey and wells have been drilled in four local areas over a length of 16 miles. Two of these wells in two separate areas contain large volumes of gas and a third contains oil in a Lower Cretaceous sand, but has not so far yielded commercial volumes because of water troubles. In the fourth area, at Borradaile, 6 miles east of Vermilion, oil of 14° to 15° A.P.I. has been found in several wells drilled to a productive sand in the Lower Cretaceous at a depth of about 1825 to 1850 ft. One of these wells is said to be flowing at 10 to 15 bbl. a day, whereas the discovery well, Battleview No. 2, when pumped has yielded at the rate of 30 to 40 bbl. a day.

Lloydminster.—Lloydminster field is on the boundary between Alberta and Saskatchewan. Wells on the Saskatchewan side are supplying gas for the town of Lloydminster and several wells have given some oil but have been operated only periodically because of various troubles. One well drilled in Alberta on the west side of the field in 1940 failed to find any production and has been abandoned.

Pouce Coupe, Peace River Area, Alberta.—After being shut down in the winter the Guardian well in the Pouce Coupe area of Alberta was resumed in June 1940 at a depth of 5459 ft. This well encountered at 4774 ft. limestone believed to be of Triassic age containing some oil shows. At the end of 1940, the well was at a depth of 6640 ft. This is the first well in western Canada from which Triassic has been reported, although beds of this age at least 3000 ft. thick are known from the foothills on Peace River 100 to 125 miles to the west.

Ontario.—Drilling in Ontario has been mostly for natural gas in the southwestern peninsula between lakes Huron, Erie and Ontario. No new fields were found in 1940 but considerable drilling was done in the Malahide field, Elgin County, and in Kent and Haldimand Counties. No new oil discoveries were made.

Gaspé, Quebec.—In Gaspé peninsula a well started by Imperial Oil Co. in 1939 was completed at a depth of 5995 ft. without discovering oil or gas in commercial volumes. Seepages of oil from the Devonian rocks have long been known in Gaspé and the well started in rocks of this age and may have drilled into Silurian beds under the Devonian but the age is uncertain. The structure in this part of Gaspé is a continuation of the Appalachian system of folding, and in the area where the well was drilled there are many anticlines, some of which were inadequately tested by wells drilled about 50 years ago and from a few of which small volumes of oil were obtained.

Petroleum Development in Colombia during 1940

By O. C. Wheeler,* Member A.I.M.E.

(New York Meeting, February 1941)

Production in Colombia attained a new high during 1940 when it reached a total of 25,607,976 bbl. Of this amount, the Tropical Oil Co. produced 21,426,492 bbl., including 268,586 bbl. of petroleum condensate, and the Colombian Petroleum Co. produced 4,181,484 bbl. from its Barco property.

The wildcatting program of different companies in the Magdalena Valley that was initiated during the previous year was continued but with results that were decidedly disappointing. Ten wells were drilled in the Magdalena Valley between the approximate latitudes of Puerto Wilches and Puerto Berrio and nine of these were dry; the tenth was a small producer of no commercial importance. The prospects of finding new fields in the Magdalena Valley thus received a serious setback, since some of the tests drilled were on well developed surface structures. The prospects of the Valley, however, have by no means been exhausted and drilling operations are being continued on other prospects. One additional wildcat was drilled outside the Magdalena Valley on the Colombian Petroleum Company's Barco Concession, which brought to 11 the total number of wildcats drilled in Colombia during the year. This well, known as

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* Chief Geologist, International Petroleum Co. Ltd., Toronto, Ont., Canada.

Table 1.—*Oil and Gas Production in Colombia*

Line Number	Field, *Department*	Year of Discovery	Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells				Repressuring Operation[d]
			To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Producing Gas[c]	
1	Infantas, *Santander*	1918	127,044,093	4,033,090			470	0	0	0	50[1]
2	La Cira, *Santander*	1926	144,459,631	17,393,402			675	75	0	0	
3	Las Monas, *Santander*	1926									
4	Petrolea (North Dome), *Santander del Norte*	1933	5,879,332	4,151,124	1,860	1,520	99	29	0	3	
5	Petrolea (South Dome), *Santander del Norte*	1937	5,549	895			1	0	0	0	
6	Rio de Oro, *Santander del Norte*	1937					10	1	0	0	
7	Carbonera, *Santander del Norte*	1939	36,402	28,463			3	2	0	0	
8	Tres Bocas, *Santander del Norte*	1940	1,002	1,002			1	1	0	0	
9	Totals		277,426,009	25,607,976			1,259	108	0		

[c] Footnotes to column heads and explanation of symbols are given on page 256.

[1] Number of repressuring key wells.

Tres Bocas No. 1, was drilled to 5400 ft. and plugged back to 3960 ft., where it was reported to have made a small producer.

Exploratory work seemed to taper off during the year, as a combined result perhaps of world conditions, completion of programs and the adverse results obtained in wildcatting. Some additional concessions were taken up and others dropped, as shown in Table 3.

Operating Companies

Socony Vacuum Oil Co.

The Socony Vacuum Oil Co. of Colombia completed three wildcats in its Restrepo Concession. Narino No. 3 was spudded in the Turin formation of Pliocene age, 1 km. west of Narino No. 1, and was abandoned late in June in the Giron formation (Jurassic or older) at a depth of 10,740 ft. Peralonso No. 1, located 13 km. northeast of Narino No. 1, was abandoned in June at a depth of 9274 ft. in the lower Chuspas of Oligocene age. The surface formation is the Magdalena of Pleistocene age. On the Las Monas structure, Las Monas No. 2 was suspended at a total depth of 6984 ft. in steeply dipping beds of the La Paz formation of upper Eocene age. The Las Monas structure produced a small amount of oil, which was used as fuel.

Colombian Petroleum Co.

Drilling and general development operations were conducted by the Colombian Petroleum Co. on its Barco concession, on the frontier of Venezuela southwest of Lake Maracaibo. The property was on a steady producing basis and over the 12-month period the average daily production was 11,456 bbl.

Petrolea North Dome Structure.—The Petrolea structure is a faulted asymmetrical anticline with the steep flank on the west. The first well drilled on the North Dome structure was Petrolea No. 1, drilled by the Colombian Petroleum Co. in 1933. As of Jan. 1, 1941, 99 wells had been drilled.

Petrolea South Dome.—The Petrolea South Dome, which is a continuation of the Petrolea anticline and separated by a

TABLE 1.—(*Continued*)

Line Number	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft.: Top Prod. Zone	Depth, Avg. Ft.: Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1		0.90	A, B, C zones	Olig, Eoc	S	15–22	400–2,200	1,000–2,600	50–200	AF	Cretaceous	4,048
2	25.1	0.90	A, B, C zones	Olig, Eoc	S	15–25	400–3,950	600–4,294	50–175	AF	Cretaceous	8,051
3			Chuspas	Olig	S					AF	Cretaceous	
4	39.1–47.1		La Luna; Ostrea Bed; Zones 1, 2, 3, 4; Uribante	Cre	LS		130–1,180			AF	Basal Zone IV and top of Uribante	
5	37.7		Zone III	Cre	LS		1,350			A	Cretaceous L	
6	39.7		Catatumbo Rio de Oro	Eoc, Cre	S		1,100–1,400			AF	Catatumbo	6,717
7	21.5		Los Cuervos Barco	Eoc	S		800–1,720		10	AF	Barco	2,722
8	30.6		Barco	Eoc	S		3,900			A	Barco	5,400
9												

saddle from the North Dome, saw no activity during 1940. Seven wells have been drilled on this structure, only one of which was completed as a producer, and this well still continues to produce oil.

Carbonera.—On the Carbonera fault structure two wells were completed in 1940, giving a total of three wells on this structure, all of which are producing from the Tertiary. The gravity of the oil is approximately 22.0° A.P.I.

Tres Bocas.—Tres Bocas No. 1, a wildcat, was completed on the Tres Bocas structure during 1940. This well was drilled to a total depth of 5400 ft. and was plugged back and completed as a small producer in the Barco sandstone at a depth of 3960 ft. The gravity of the oil is 30.6° A.P.I. Additional drilling is planned on this structure.

Socuavo.—One wildcat was drilling at a depth of 4838 ft. at the end of the year.

Rio de Oro.—One well was completed at Rio de Oro in the Catatumbo formation and one deepened to the Rio de Oro during 1940. The structure is a narrow, tight anticline considerably faulted. As of Jan. 1, 1940, 13 wells had been drilled.

Refinery.—A refinery of 500 bbl. daily capacity is in operation at Petrolea. The products are being consumed on the Concession and distributed locally.

Pipe Line.—The South American Gulf Oil Co. pipe line extends from Petrolea to the Covenas terminal, a distance of 263 miles. The line is constructed of 12-in. welded steel pipe with a present capacity of approximately 25,000 bbl. per day. The highest point traversed by the line is 5286 ft. There are pumping stations at Petrolea, Tarra, and Convencion, and a relief station at El Carmen. The present storage capacity for the pipe line is 1,234,578 bbl.; 331,578 bbl. at Petrolea and 903,000 bbl. at Covenas.

Cia. de Petroleo Shell de Colombia

The Cia. de Petrolea Shell de Colombia carried on drilling operations on two national concessions:

1. On its concession north of Rio Ermitano, acquired from Bernardo Mora, two exploratory wells were completed. Monte Oscuro No. 1 was started in the Armas formation of the Oligocene. A thrust fault was penetrated at 2986 ft. and the well was completed as a dry hole at a total depth of 9103 ft. in underthrust La Cira formation of the Oligocene. Monte Oscuro No. 2 also started in the Armas formation,

TABLE 2.—*Summary of Drilling Operations in Colombia*

Important Wildcats Drilled in 1940

	Department	Location			Total Depth, Ft.	Surface Formation
		Survey	Lat.	Long.		
1	Santander	Infantas E 5	DeMares Concession		6,805	Colorado (Oligocene)
2	Santander	La Puerta No. 1	DeMares Concession		7,570	Real (Miocene)
3	Santander	San Fernando 2	Sociedad Nacional del Carare Concession		9,272	Real (Miocene)
4	Santander	Monte Oscuro 1	Sociedad Nacional del Carare Concession		6,550	Colorado (Oligocene)
5	Santander	Baul No. 1	6°14′19.7″ N.	0°18′23.2″ W. of Bogota	7,447	Mesa (Pliocene)
6	Santander	Monte Oscuro 1	6°9′44.4″ N.	0°13′39.1″ W. of Bogota	9,103	Armas (Oligocene)
7	Santander	Monte Oscuro 2	6°11′9.1″ N.	0°13′41.2″ W. of Bogota	3,016	Armas (Oligocene)
8	Santander	Las Monas No. 2	Restrepo Concession		6,984	Oligocene
9	Santander	Narino No. 3	Restrepo Concession		10,740	Turin (Pliocene)
10	Santander	Peralonso No. 1	Restrepo Concession		9,274	Magdalena (Pleistocene)
11	Santander del Norte	Tres Bocas 1	Barco Concession		5,400	

and was completed as a dry hole at a total depth of 3016 ft. in underthrust Real formation of the Miocene, after passing through a thrust fault at 2454 feet.

2. On its concession west of the Rio Carare, drilling activities were initiated and the well known as Puerto Parra No. 1 was near completion at the end of the year. This well was started in the Mesa formation of the Pliocene and latest reports indicate that it will be abandoned as a dry hole at a total depth of 10,929 ft. in the Oligocene. The coordinates of this test are latitude 6°39′09.1″ N.; longitude 0°00′17.0″ W. of Bogota.

Cia. Colombiana de Petroleos El Condor

Drilling on this company's concession southeast of Puerto Berrio was continued on the well known as Baul No. 1. The test started at the surface in the Mesa formation of the Pliocene and was abandoned as a dry hole at a depth of 7447 ft., in igneous basement. Because of disappointing results of drilling, this concession, acquired from the Consorcio Minero Nacional, was surrendered and returned to the Government at the end of the year.

Sociedad National del Carare

The Sociedad National del Carare completed the testing of its San Fernando well No. 2 drilled during the preceding year, and abandoned it during the month of January at a depth of 9272 ft. The well was drilled at the crest of a well defined anticlinal closed fold and the absence of production was highly disappointing. The same company drilled and completed its Monte Oscuro No. 1 to a depth of 6550 ft., where it was abandoned in the basal sands of the Tertiary. This well was likewise drilled on a strongly developed structure and is considered to have eliminated the prospects of finding commercial production on that uplift. The company surrendered its con-

TABLE 2.—(*Continued*)

Important Wildcats Drilled in 1940

	Deepest Horizon Tested	Drilled by	Initial Production per Day, Oil, U. S. Bbl.	Remarks
1	La Paz (Eocene)	Tropical Oil Co.	0	Dry
2	Umir (Cretaceous)	Tropical Oil Co.	0	Dry
3	La Paz (Eocene)	Sociedad Nacional del Carare	?	Small producer (abandoned)
4	La Paz (Eocene)	Sociedad Nacional del Carare	0	Dry
5	(Finished in igneous basement)	Cia. Colombiana de Petroleos el Condor	0	Dry
6	La Paz (Eocene)?	Cia. de Petroleo Shell de Colombia	0	Dry
7	La Paz (Eocene)?	Cia. de Petroleo Shell de Colombia	0	Dry
8	Chuspas (Oligocene)	Socony-Vacuum Oil Co. of Colombia	0	Dry
9	Giron (Jurassic or older)	Socony-Vacuum Oil Co. of Colombia	0	Dry
10	Chuspas (Oligocene)	Socony-Vacuum Oil Co. of Colombia	0	Dry
11	Barco (Eocene)	Colombian Petroleum Co.	?	Plugged back to 3960 ft. small producer

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940		
Number of oil wells completed during 1940	107	1
Number of gas wells completed during 1940	0	0
Number of dry holes completed during 1940		10

TABLE 3.—*Status of Applications*

Number on Fig. 1	Company	District	Date Accepted	Area, Hectares
	APPLICATIONS ACCEPTED IN 1940 BUT CONCESSIONS NOT YET GRANTED			
1	Texas Petroleum Co.	Rio Negro	Apr. 12	19,920
2	Jaime Samper	Pivijay	Apr. 12	43,500
3	Alberto Isaza	Rio Lebrija	May 16	49,770
4	Cia. de Petroleos La Perla de Colombia, S. A	Rio Ariari	June 18	99,523
5	Gonzales Mejia	Rio Upia	Nov. 13	94,973
6	Luciano Restrepo	Rio Sogamoso	Dec. 13	19,718
7	Cia. Colombiana de Petroleo Occidental, S. A	Rio Ariari	Dec. 13	49,456
	APPLICATIONS ACCEPTED BEFORE 1940 BUT CONCESSIONS NOT YET GRANTED			
8	Francisco Rocha Vargas	Rio Carare	Jan. 16/39	3,383
9	Mora & Pelaez Hnos	Rio Minero	Mar. 16/38	42,336
10	Carlos Arturo Torres Pinzon	Rio Sogamoso	May 9/39	12,609
11	Sindicato de Inversiones, S. A.	Rio Lebrija	June 4/37	45,905
12	Frederick R. Ryan	Rio Sogamoso	June 22/38	19,328
13	Francisco Lascerna	Rio Minero	July 7/39	18,354
14	Hernando Franco	Rio Lebrija	July 25/39	45,634
15	Luis Alberto Villamizar	Rio Simiti	Aug. 8/39	22,995
16	William Neilson	Puerto Berrio	Aug. 17/39	45,006
17	Cia. Anglo-Colombiana de Petroleos	Rio Ariguani	Aug. 21/39	47,784
18	Cia. de Petroleo La Perla de Colombia	Rio Ariguani	Aug. 22/39	49,985
19	Hernando Salazar	Puerto Wilches	Sept. 21/39	9,304
20	Roberto Pena	Rio Sinu	Oct. 5/38	44,954
21	Antonio Borda Carrizosa	Rio Metica	Nov. 15/39	99,938
22	Cia. Anglo-Colombiana de Petroleos	Rio Ariari	Nov. 22/39	99,319
23	Antonio Jose Castro Borrero	Rio Patia	Nov. 25/39	16,540
24	Texas Petroleum Co.	Rio Upia	Dec. 1/38	100,000
25	Jaime Gutierrez	Buenavista	Dec. 5/38	49,199
26	Carlos de Narvaez	La Dorada	Dec. 5/38	36,015
27	Cia. de Petroleo La Estrella de Colombia	Rio Ariguani	Dec. 6/39	48,568
28	Cia. Petrolera de Bogota	Rio Cesar	Dec. 7/39	47,853
29	Martin Theves	Rio Ite	Dec. 13/39	49,580
30	Giovanni Serventi	Rio Nare	Dec. 13/39	49,431
	APPLICATIONS ACCEPTED AND LATER SURRENDERED			
			Date Surrendered	
31	Manuel Toro	Rio La Miel	Dec. 16/40	5,091
	CONTRACTS TERMINATED AND AREAS RETURNED TO THE NATION IN 1940			
32	Luciano Restrepo (transferred to Socony-Vacuum Oil Co. of Colombia, Feb. 22, 1935)	Rio Sogamoso	Nov. 13/40	49,232
33	Consorcio Minero Nacional (transferred to Cia. Colombiana de Petroleos El Condor, Mar. 3, 1938)	Rio Ermitano	Nov. 22/40	44,258
34	Sociedad Nacional del Carare (under joint exploration with Tropical Oil Co.)	Rio Carare	Dec. 2/40	34,783
	CONTRACTS EFFECTIVE AS OF DEC. 31, 1940			
			Date Awarded	
35	Cia. de Petroleo Shell de Colombia	Rio Carare	Mar. 2/38	49,906
36	Cia. de Petroleos del Carare	Rio Lebrija	Mar. 15/38	49,636
37	Salvador Camacho Roldon	Rio Simiti	May 20/40	49,468
38	Juan de Dios Gutierrez (transferred to Tropical Oil Co., Feb. 10, 1940)	Rio Cimitarra	May 23/39	16,927
39	Daniel A. Del Rio (transferred to Cia. Petrolera de Bogota, June 2, 1939)	Barranquilla	May 25/38	20,141
40	Richmond Petroleum Co.	Rio Guayabero	June 26/40	100,000
41	Cia. de Petroleo Shell de Colombia	Rio Ariari	Aug. 10/39	99,975
42	Socony-Vacuum Oil Co. of Colombia	Rio Sogamoso	Aug. 30/39	27,040
43	Cia. Colombiana de Petroleos El Condor	Rio Cimitarra	Sept. 15/38	47,810
44	Bernardo Mora (transferred to Cia. de Petroleo Shell de Colombia, Oct. 27, 1937)	Rio Ermitano	Sept. 28/37	50,000
45	Wm. A. MacCarthy (transferred to Cia. de Petroleos de Carare May 10, 1940)	Rio Paturia	Nov. 24/39	20,520
46	Rene Granger (transferred to Richmond Petroleum Co. of Colombia, Dec. 12, 1940)	Rio Cesar	Nov. 28/40	18,514
47	Carlos Botero Mejia	Puerto Wilches	Dec. 13/39	39,537
48	Evaristo Obregon Arjona (transferred to Cia. de Petroleos La Perla de Colombia, Jan. 15, 1940)	Rio Ermitano	Dec. 15/39	36,757
49	Cia. de Petroleos del Valle del Magdalena	Rio Cimitarra	Dec. 16/39	32,880

cession and was dissolved at the end of the year.

Tropical Oil Company Ltd.

The Tropical drilled 77 wells on its De Mares Concession during the year, of which 75 were in La Cira field and 2 were wildcats. The wildcats were known as La Puerta No. 1, which is about 9 km. east of Barranca Bermeja, and E-5, which is about the same distance east of the center of the Infantas field. Both these wells were complete failures. Of the 75 La Cira completions, three were dry holes. The initial production of the 72 producers averaged 378 bbl. per day. The production from Infantas and La Cira fields totaled 4,033,090 bbl. and 17,393,402 bbl., respectively, in which figures are included 143,076 bbl. of petroleum condensate added to crude from Infantas and 125,510 bbl. from La Cira.

FIG. 1.—PETROLEUM AND GAS FIELDS, COLOMBIA.

Petroleum Developments in Ecuador during 1940

By Cecil Hagen,* Member A.I.M.E.

All of the production for Ecuador during 1940 came from the Santa Elena Peninsula, Province of Guayas; the major portion coming from the Ancon field, which is controlled mostly by Anglo-Ecuadorian Oilfields, Ltd. A small amount was produced from the shallow pumpers and pozos, or oil pits, at Cautivo-Achallan, Carolina, Santa Paula, Concepcion, El Tambo and Mina Tigre.

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* Consulting Geologist, Houston, Texas.

Considerable exploration was carried on in the country during 1940 and numerous concessions were in force, as shown by the accompanying map. Anglo-Saxon continued its exploratory work in the Oriente by surface geological methods and some geophysical surveys. It is understood that this concern did considerable airplane mapping. International Petroleum, on its large concessions between the Andes and Pacific Coast, did considerable surface work as well as some geophysical. No exploratory test wells were drilled by either of these

Table 1.—*Oil and Gas Production in Ecuador*

Line Number	Field, Santa Elena County, Province of Guayas	Age, Years	Area Proved, Acres: Oil	Area Proved, Acres: Gas[b]	Total Oil Production, Bbl.: To End of 1940	Total Oil Production, Bbl.: During 1940	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]
1	Ancon H.C.T.[1]	20	*y*	0	*y*	1,465,337	20,*xxx*	*y*	196	8	1	*y*	1*xx*	0
	Ancon L.C.T.		*y*	0	*y*	303,460	*y*	*y*	380	19		*y*	2*xx*	0
		20	1,2000	0	22,471,986	1,768,797	20,*xxx*	2,117	576	27	1	*y*	4*xx*	0
2	Cautivo-Achallan	18	2,*xxx*	0	566,385	71,691	*xxx*	*x*	181	9	99	0	82	0
3	Carolina and Santa Paula	*y*	2,000	0	613,785	79,256	*xx*	*x*	64	9	43	0	21	0
4	Concepcion	10	*y*	0	136,598	52,836	*xx*	*x*	15	3	1	0	14	0
5	El Tambo	9	*x*	0	8,816	956	0	0	6	0	2	0	4	0
6	"Tigre"	3	200	0	466,525	400,903	*xx*	*x*	12	6	0	*y*	*y*	0
7	Total				24,264,095	2,374,439	20,*xxx*	2,*xxx*	854	54	146	*y*	5*xx*	0

Line Number	Oil Production Methods, End of 1940, Number of Wells: Flowing	Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Avg. at End of 1940	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Producing Formation: Name	Age[e]	Character[f]	Porosity[g]	Depth Avg. Ft.: Top Prod. Zone	Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Deepest Zone Tested to End of 1940: Name	Depth of Hole, Ft.
1	37	12*x*	*y*	1,050	40	0.012	Atlanta	Eoc	S	Fis	3,000	6,000	2,500	AF	San Jose sandstone	8,053
	0	2*xx*	*y*	0	36	0.012	Socorro	Eoc	S	Por	1,200	1,800	600	*y*		
	37	4*xx*														
2	2	80	200	100	29	*y*	Socorro(?)	Eoc(?)	S	Fis	750	1,000	250	*y*	Socorro(?)	1,295
3	2	19	145	90	28	*y*	Socorro(?)	Eoc(?)	S	Fis	632	836	200	*y*	Socorro(?)	1,506
4	5	9	*y*	*y*	38	*y*	Atlanta	Eoc	S	Fis	*y*	4,000	*y*	*y*	Atlanta	4,500
5	0	4	*y*	*y*	*y*	*y*	Socorro	Eoc(?)		*y*	*y*	*y*	*y*	*y*	Socorro	1,300
6	10	2	1,000	1,000	39	0.0*x*	Atlanta	Eoc	S	Fis	2,900	4,300	400	*y*	Atlanta	4,319
7	56	5*xx*														

[b] Footnotes to column heads and explanation of symbols are given on page 256.

[1] H.C.T. means the deep zone for High Cold Test crude oil. L.C.T. means the shallow zone for Low Cold Test crude oil. They occur in the same area.

companies; however, the latter is planning a deep test soon.

Some surface work was carried on in the Province of Esmeraldas on some of the smaller concessions in the vicinity of Esmeraldas. Several Japanese geologists were reported doing geological work northwest of this town.

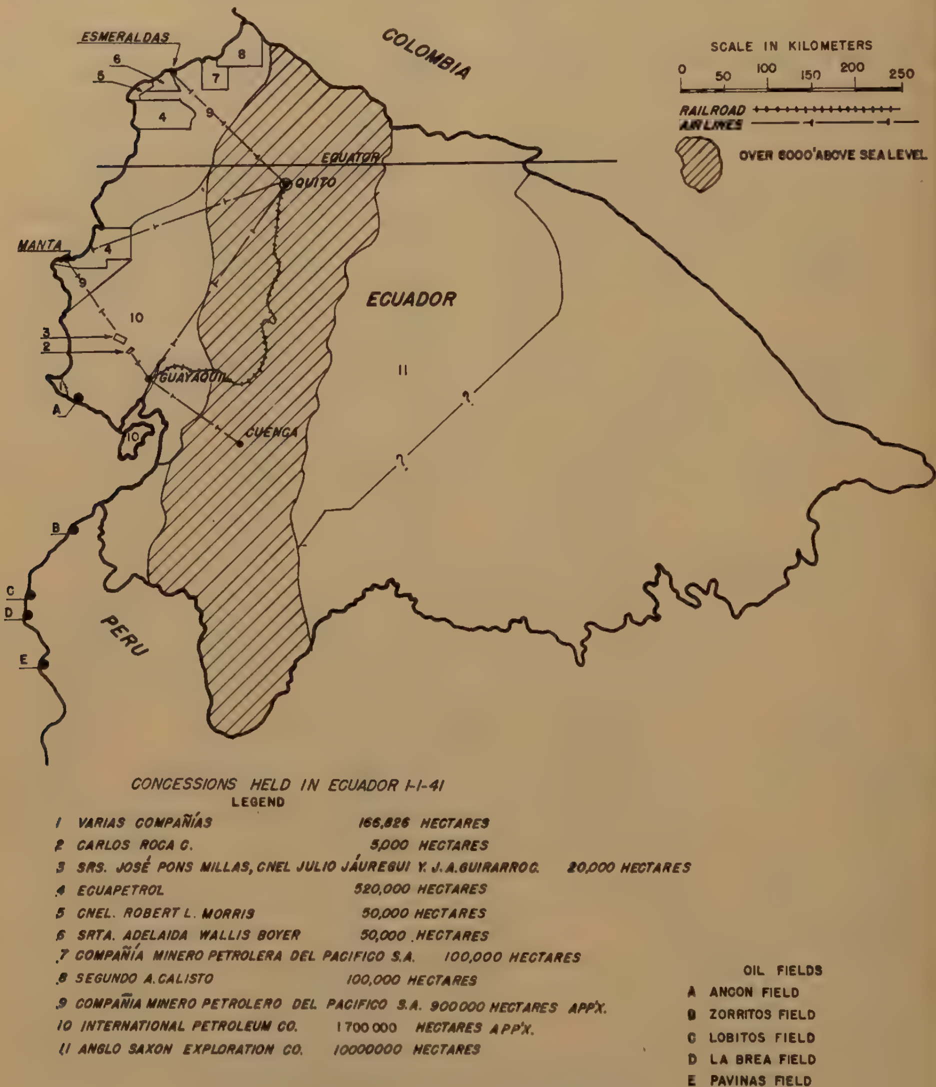

FIG. 1.—CONCESSIONS HELD IN ECUADOR JAN. 1, 1941.

Petroleum Development in Mexico during 1940

By J. W. Ristori,* Associate Member A.I.M.E.

During the year 1940, production of crude oil in Mexico totaled 43,914,000 bbl., or 2,776,000 less than in 1937, the year before expropriation. The 1940 output was 1,200,000 higher than in the previous year. In 1937, Poza Rica production accounted for 40 per cent of the total, while in 1940 this percentage had increased to 65.

Table 1.—*Production of Crude Oil in Mexico*
Thousands of Barrels

District	1937	1938	1939	1940	Total to End of 1940
Panuco (11° to 14° A.P.I.)	9,806	5,344	5,516	6,188	752,209
Southern (20° to 24° A P.I.)	8,292	4,230	4,625	3,769	1,027,743
Poza Rica (33° to 34° A.P.I.)	18,634	22,021	26,322	28,358	124,438
Tehuantepec (32.5° A.P.I.)	9,958	6,684	6,316	5,599	111,317
	46,690	38,279	42,779	43,914	2,015,707
Daily average	127,919	104,875	117,203	119,982	

Table 2.—*Exports of Crude Oil and Its Products (Including Ship's Bunkers)*
Thousands of Barrels

Crude and Products	1937	1938	1939	1940
Panuco crude (11° to 14° A.P.I.)	5,887	1,503	4,227	2,417
South Fields crude (20° to 24° A.P.I.)	395	149	1,044	1,124
Poza Rica crude (33° to 34° A.P.I.)	874	3,025	7,071	11,074
Crude gasoline	4,388	2,775	1,488	454
Gas oil	3,234	3,109	1,783	2,854
Fuel oil	5,663	2,473	2,922	1,872
Asphalt	3,049	1,000	481	509
Kerosene	688	241	42	269
Lubricants	400	88	2	1
Total	24,578	14,363	19,060	20,574

Declines in exports of Panuco crude, fuel oil and gasoline were recorded but these were more than offset by increased exports of 4,000,000 bbl. of Poza Rica crude, which was the approximate amount shipped to Sinclair during 1940 under the terms of the settlement. Over-all exports increased by 1,500,000 bbl. over the preceding year.

The outstanding development regarding the destination of Mexican exports in 1940 was the increase of 10,000,000 bbl. in the exports to the United States. Exports to Germany ceased toward the end of 1939 and to Italy in the second half of 1940.

During the year 1940 the Sinclair interests and the Mexican Government settled their expropriation question. By the terms of the settlement Sinclair is to be compensated by cash payments and oil-purchase contracts.

On Dec. 1, 1940, Avila Camacho was inaugurated President of Mexico for a term of six years. Among his first acts following his election were:

1. A proposal to change the Constitution to restore Supreme Court Judges' terms to life tenure. This has been ratified by both chambers of the Mexican Congress and is now before the legislatures of the States of Mexico for ratification.

2. The taking away of the administration of the railroads from labor and restoration to the State.

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* Cities Service Co., New York, N. Y.

TABLE 3.—*Exports of Petroleum by Destination*

Destination	1937		1938		1939		1940	
	Exports	Per Cent	Exports	Per Cent	Exports	Per Cent	Exports	Per Cent
Australia	705	2.9	161	1.1	123	0.6	85	0.4
Belgium	610	2.5	808	5.6	23	0.1		
Brazil	419	1.7	48	0.3	126	0.7		
Chile	213	0.9	5		54	0.3	79	0.4
Cuba	485	2.0	292	2.0			127	0.6
Netherlands West Indies	4,299	17.5	1,097	7.6				
England	5,411	22.0	1,857	12.9	19	0.1		
France	156	0.6	243	1.7	16	0.1		
Germany	2,521	10.3	5,408	37.7	6,343	33.3		
Guatemala	131	0.5	1					
Italy	186	0.8	350	2.5	4,790	25.1	2,991	14.5
Japan			233	1.6	188	1.0	760	3.7
Scandinavia	352	1.4	365	2.6	398	2.1	94	0.5
South Africa	162	0.7						
United States	6,856	27.8	2,683	18.7	5,456	28.6	15,722	76.4
Uruguay	70	0.3	69	0.5	226	1.2	69	0.4
Others	488	2.0	265	1.9	308	1.6	108	0.5
Bunkers	1,514	6.1	478	3.3	990	5.2	539	2.6
	24,578	100.0	14,363	100.0	19,060	100.0	20,574	100.0

Petroleum Development in Peru during 1940

BY O. B. HOPKINS*

THE total production of oil in Peru in 1940 was 12,127,135 bbl., or about 10 per cent less than in 1939. Most of the reduction can be attributed to the fact that the export market under war conditions is much restricted and naturally is more than ordinarily competitive.

DEVELOPMENT AND EXPLORATION IN OLDER AREAS

As evidenced by Table 1, almost all production continued to come from the three established fields in coastal northwestern Peru.

Zorritos Field.—Exploration in this small field, which was purchased by the Peruvian Government in 1939, continued with that in near-by areas in the adjoining National Reserve. Several wells were drilled, regarding which details are not as yet available. It is estimated that the production rate for a total of some 45 old and 15 new wells approximated 200 bbl. per day, or about 3 bbl. per well per day.

Lobitos Fields.—The Lobitos area produced 2,435,504 bbl.; about 10 per cent less than the amount for 1939.

La Brea-Parinas.—This property of International Petroleum Co. continued to account for nearly 80 per cent of Peru's production. During the year, drilling was stepped up to 139 wells, as compared with 73 wells completed in the previous year; 123 were producers and aggregated a total of 287,867 ft. Of this total, more than 85 per cent was drilled by rotary tools, which are steadily displacing other equipment.

Although most of these wells were drilled in the proved or semiproved areas, eight

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TABLE 1.—*Oil and Gas Production in Peru*

Line Number	Field, *Department*	Year of Discovery	Area Proved, Acres		Total Oil Production, Bbl.		Total Gas Production, Millions Cu. Ft.		Number of Oil and/or Gas Wells						Oil-production Methods, End of 1940	
										During 1940		End of 1940			Number of Wells	
			Oil	Gas[b]	To End of 1940	During 1940	To End of 1940	During 1940	Completed to End of 1940	Completed	Abandoned	Temporarily Shut Down	Producing Oil[c]	Producing Gas[c]	Flowing	Artificial Lift
1	LaBrea-Parinas, *Piura*	1889	y	y	211,962,466	9,626,831	x	x	3,250	139	16	166	2,091	16	110	1,981
2	Lobitos and Restin, *Piura*	1904	y	y	49,064,191[1]	2,435,504[1]	x	x	y	y	y	y	y	y	y	y
3	Zorritos, *Tumbes*	1883	y	y	3,297,502[1]	64,800[1]	x	x	y	y	y	y	y	y	y	y
4	Pirin (Huacane), *Puno*	x			y	y	x	x	y	y	y	y	y	y	y	y
5	Pachitea, *Huanuco*	1939	y	y	y	y	x	x	y	y	y	y	y	y	y	y
6	Totals				264,324,159[1]	12,127,135[1]										

[b] Footnotes to column heads and explanation of symbols are given on page 256.
[1] Estimated.

were of an exploratory nature. The most successful was well 3095, which opened up a new area that is now known as the Rio Bravo pool, in the northern part of the property. The discovery well had a flowing initial production of 1072 bbl. per day from a depth of 2375 feet.

Work was started on a deep test well (No. 3115) designed to determine whether production can be secured, not only from the Tertiary, to which so far it has been confined, but also from the Cretaceous. At the end of 1940 this well was drilling at 9200 ft. in beds of Upper Cretaceous age.

As of Dec. 31, 1940, on the Estate there were 2107 wells still classed as producers, out of a total of 3250 wells completed to that date.

A recently issued official government report (Table 2) shows the total number of wells in Peru as of Dec. 31, 1939.

Development and Exploration in Newer Areas

Pirin.—At the time of writing no information on this activity in the Lake Titicaca region is available. It is presumed that any activity there was on a small scale.

Pachitea Region.—Development in eastern Peru is confined entirely to the Ganso Azul Company's Agua Caliente anticline, which is near the River Pachitea and some 20 miles upstream from its confluence with the River Ucayali (Fig. 1). This structure strikes northwest-southeast and is about 15 miles long by 7 miles wide. The crest of the

Table 1.—(*Continued*)

Line Number	Reservoir Pressure, Lb. per Sq. In.		Represuring Operation[d]	Character of Oil		Producing Formation								Deepest Zone Tested to End of 1940	
	Initial	Avg. at End of 1940		Gravity A.P.I. at 60°F., Weighted Average	Sulphur, Per Cent	Name	Age[e]	Character[f]	Porosity[g]	Depth, Avg. Ft. Top Prod. Zone	Depth, Avg. Ft. Bottoms Prod. Wells	Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
1	y	y	PM, RP	38.1	y	Verdun, Talara, Parinas, Salina, Negritos	Eocene	S	y	y	y	y	AF	Eocene	
2	y	y	y	y	y	Terebratula, Lower Caverno	Eocene	S	y	y	y	y	AF	Probably Cretaceous	
3	y	y	y	y	y	Zorritos	Miocene	S	y	y	y	y	MF?	y	
4	y	y	y	y	y	y	y	y	y	y	y	y	y	y	
5	y	y	y	y	y	y	y	y	y	y	y	y	A	Lower Cretaceous	3,130
6															

Table 2.—*Government Figures*

	International Petroleum	Lobitos	Zorritos	Pirin	Agua Caliente	Totals
Producers:						
Oil	1,974	774	46	1	3	2,798
Gas	16	1				17
Water	3					3
Abandoned	1,118	267	375	1	1	1,762
Total drilled	3,111	1,042	421	2	4	4,580
Drilling	25	17	6	2	1	51
Footage drilled in 1939	198,447	95,009	20,588	1,270	3,642	318,956
Total footage drilled to end of 1939	5,205,795	2,447,676	482,374	1,270	6,672	8,143,887

fold is relatively wide and flattened. To the northeast, dips are as high as 25° to 30° and on the southwest flank they are somewhat less.

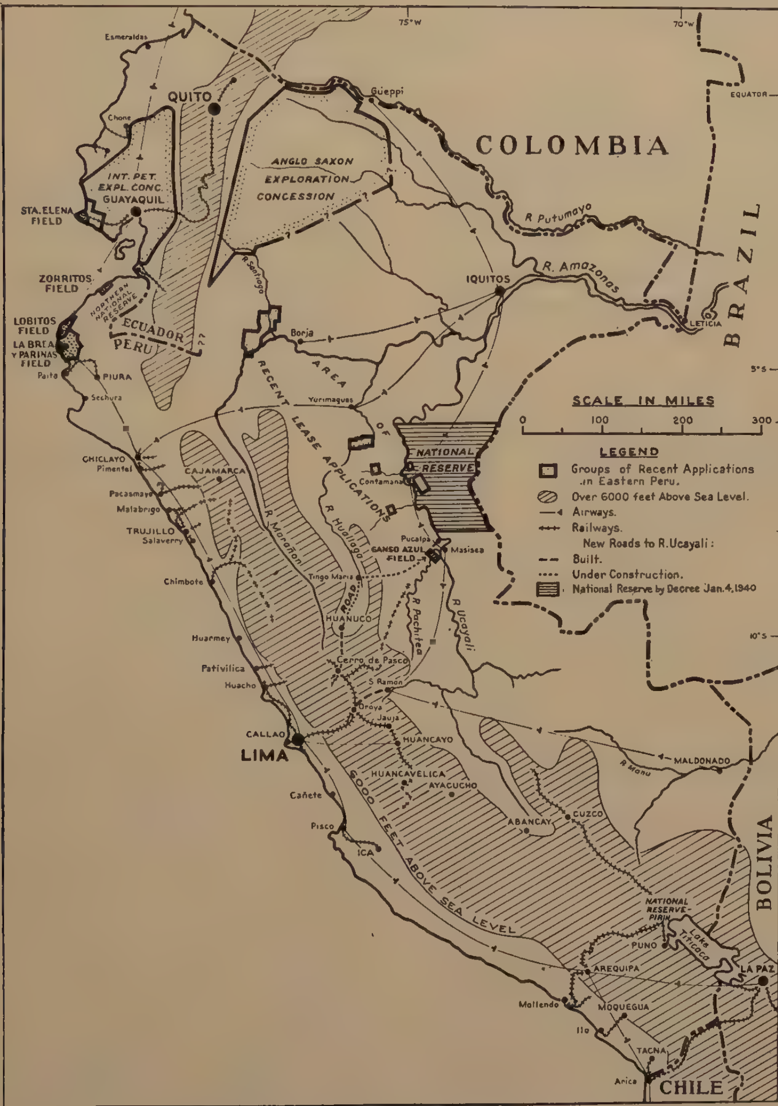

FIG. 1.—PETROLEUM AND GAS FIELDS IN PERU.

The surface formations are higher Cretaceous in age, while those immediately below are regarded as Comanchian. The first 1000 ft. consist of hard sands and siltstones with interbedded shales, which increase in proportion with depth. From 1000 to 1260 ft., there are varying thicknesses of interbedded shales, sands, grits and volcanic ash. Of these, approximately 150 ft. are saturated oil sands. From 1260 to 1454 ft., the formations are mainly sandstones, grits and ashy materials, with salt water below 1250 ft. and thin oil sand at about 1425 ft. At 1454 ft. there is a very

hard blue-gray limestone, which continues to about 3150 feet. The data above are for well No. 1, which was drilled, presumably, near the apex of the anticline.

Five wells have been drilled and one is rigging up. Data on these are given in Table 3.

The oil, which is of 46° A.P.I. gravity, is accompanied by very little gas, the flow apparently being due to a hydrostatic head in the same sands, which reach back into the hills some 30 or 40 miles to the west.

The temperature of the oil is approximately 165°F. as it is produced. There is no ready explanation of this rather excessive temperature.

Leasing, and New Government Reserve

Although little or no new leasing activity is reported in any part of Peru, it is noted that the Government created a new National Reserve of approximately 8,000,000 acres in eastern Peru, in the region near the Ganso Azul's concession (Fig. 1).

Acknowledgments

For the information on the Ganso Azul activities, the writer is indebted to the kindness of Mr. J. E. Brantly, President of Drilling and Exploration Company of Los Angeles, whose company conducted these activities.

Table 3.—*Data on Ganso Azul Company's Wells on Agua Caliente Anticline, Pachitea Region, Eastern Peru*

Well No.	Approximate Location from Well No. 1A	Year Completed	Condition in January 1941	Results	Thickness of Oil Sands, Ft.	Total Depth, Ft.
1	24 ft. N.W.	1939	Standing—may deepen	Oil indicated but not discovered		3,130
1A		1939	Closed in. Is the discovery well and is bottomed in top of ash bed	Tested 350 bbl. per day on ¼-in. choke Tested 750 bbl. per day on ½-in. choke Tested 1000 bbl. per day on ¾-in. choke	90 ±	1,175
2	1.1 mi. N.W.	1939	Plugged	Found oil-bearing sand but drilled into bottom water and was plugged	35 ±	1,230
3	0.5 mi. S.E.	1939	Closed in	Tested 250 bbl. per day on ¼-in. choke	60	1,138
4	0.2 mi. S.W.	Jan. 1941	Closed in. Bottomed in top of ash bed	Tested 120 bbl. per hour through 2-in. tubing	136	
5	0.2 mi. N.E.		Rigging up			
6	1.0 mi. N.W.		Proposed			

Developments in the Principal Oil Fields of Rumania during 1940*

The activity of the principal oil fields of Rumania followed the same course as in 1939. It was marked by (1) collaboration between the various companies, particularly in exploiting oil at great depths with a view to rationalizing the exploitation and decreasing the difficulties inherent in very deep drilling; and (2) economy in the exploitation of the older pools in reducing to a minimum the cost of the extraction and working over of wells by the concentration of productive wells in groups. The pooling arrangement continued at Tintea as a measure of conservation, and exploitation of the unitized region went forward on the basis of the norms established in 1939. The same methods were applied in the fields of Liliesti, Ceptura and Boldesti.

The petroleum industry had some difficulty in providing the necessary material and the hands for work. Importation of material and machines from the United States was virtually stopped. Substitutes were provided from Germany but particularly useful were certain dispositions made by the local metallurgical industry. Despite the higher cost of the production of local material and machines, they were superior to the German product, the difference in quality justifying the higher price charged as the materials were found to be particularly adapted for the purposes of the petroleum industry. The cost of production was still further raised by the work that was imposed for national defense. The rise in costs per meter drilled was 50 per cent over those of 1939.

According to bimonthly tables furnished by the *Moniteur du Pêtrole Roumain*, the deepest well completed in 1940 was an exploratory well, No. 201 of the Concordia company, drilled at Tintea and suspended at 3338 meters. This depth was reached toward the close of 1939 and the well was not deepened in 1940 because of large deviation from the vertical.

The record for productive wells had been held by No. 429 at Tintea, drilled by Unirea to a depth of 3200 m., and in 1938 well No. 317 Cocorasti-Mislea, of the Colombia company, but these records were passed in 1940 by well No. 613 Liliesti of the Concordia company, which reached a depth of 3294 m. and had an initial production of 10 tons per day.

In 1940, the same number of wells, 11, had been drilled to a depth of over 3000 m. as in 1939. Five of these wells are at Tintea and six at Liliesti. Table 1 lists these very deep holes in the order of their depth.

TABLE 1.—*Deep Wells Drilled in Rumania in* 1940

No. of Well	Company	Field	Depth, Meters	Initial Production, Tons per Day
405	Colombia	Liliesti	3,001	10
629	Unirea	Tintea	3,005	73
426	Unirea	Tintea	3,050	48
410	Colombia	Liliesti	3,055	30
627	Concordia (Unirea)	Liliesti	3,072	75
430	Concordia (Unirea)	Tintea	3,119	30
618	Colombia	Liliesti	3,168	70
24	Steaua Romana	Tintea	3,184	18
412	Unirea	Tintea	3,211	23
613	Concordia	Liliesti	3,294	10

Production in Rumania in 1940 reached 5,813,000 tons, in contrast to 6,240,000 tons in 1939, a decline of 427,000 tons, or 6.8 per cent. Drilling reached 241,500 m., in

* Translation from *Moniteur du Pétrole Roumain* (Jan. and Feb. 1941).

contrast to 256,000 m. in 1939, which is a decline of 14,500 m., or 5.7 per cent. The reduction in production in 1939 from that in 1938 was 5.6 per cent. Between Jan. 1 and Dec. 1, 1940, production began from 93 wells, as against 104 wells in 1939 and 137 in 1938. The average depths of these wells were as follows: 13 wells below 1000 m.; 21 between 1001 and 1500 m.; 22 between 1501 and 2000 m.; 17 between 2001 and 2500 m.; 9 between 2501 and 3000 m.; 11 over 3000 meters.

TABLE 2.—*Depths of Wells*

Fields	Number of Wells That Reached the Formation	Minimum Depth, Meters	Maximum Depth, Meters
Tintea	16	1,382	3,211
Moreni	15	638	1,935
Ceptura	11	1,194	1,600
Margineni	9	1,870	2,140
G. Ocnitei	12	903	2,148
Boldesti	8	2,290	2,580
Liliesti	8	2,926	3,294
Piscuri	6	342	1,240
Mislea	3	762	1,433
Ochiuri	2	1,428	1,464
Baicoi	2	2,625	2,721
Rasvad	1	1,851	

Of the 93 wells, 12 produced from the Dacien, 2 (Margineni) from the Miocene and 79 from the Meotic. Of the 12 wells in the Dacien, 6 were at Tintea exploiting the horizon at depths varying between 1382 and 1812 m. The distribution of the wells in the various depths is shown in Table 2.

Table 3 indicates the time required to drill certain of the deeper wells in the various fields, and the meters drilled per day.

It is notable that well No. 465, Creditul Minier à Moreni, found petroleum at a depth of 1847 m. after 30 days of drilling, which is an average of 61.1 m. per day.

The following figures show the number of wells by companies: Romano Americana, 24 wells; Concordia, 14; Astra Romana, 13; Unirea, 10; Creditul Minier, 8; Steaua Romana, 7; Colombia, 6; Foraky Romanesca, 4; Prahova, 3; Petrolul Romanesc, 2; Dacia Romana Petr. Sy., 1; Continentala Petrolifera, 1.

SUMMARY BY AREAS

Tintea.—The region of Tintea was the most important drilling district for the year, with 16 new wells and a production of 1,246,000 tons, against 1,093,300 tons in 1939. Production increased therefore 14 per cent. As in the previous year, the field was the object of special attention by the companies interested—Unirea, Astra-

TABLE 3.—*Drilling Time*

Fields	Wells	Companies	Depth, Meters	Time of Drilling, Days	Average Depth Drilled per Day, Meters
Liliesti	410	Colombia	3,055	110	27.80
Liliesti	31	Concordia	2,926	130	22.50
Liliesti	430	Concordia	3,119	145	21.50
Tintea	195	Unirea	1,789	55	32.50
Tintea	191	Unirea	1,802	61	29.50
Tintea	625	Unirea	3,005	97	30.90
Tintea	24	Steaua Romana	3,184	114	27.40
Ceptura	145	Rom. Americ.	1,520	31	49
Ceptura	168	Rom. Americ.	1,360	32	42.50
Ceptura	166	Rom. Americ.	1,293	35	36.80
Margineni	507	Rom. Americ.	2,070	61	33.90
Margineni	510	Rom. Americ.	2,028	68	29.80
Margineni	5	Rom. Americ.	2,116	81	26
Boldesti	146	Astra Romana	2,570	65	39.50
Boldesti	140	Astra Romana	2,290	66	34.70
Boldesti	144	Astra Romana	2,290	67	34.20
Piscuri	118	Rom. Americ.	1,240	44	28.20
Moreni	464	Credit. Minier	1,797	51	35.20
Moreni	465	Credit. Minier	1,847	30	61.10
Moreni	462	Credit. Minier	1,897	64	29.60
Gura Ocnitei	70	Concordia	903	41	22

Romana, Concordia and Steaua Romana—the majority of the work in drilling being executed on the basis of agreement and division of the daily production. Most intense activity was exhibited by Unirea, which drilled six new wells and obtained production in the neighborhood of 370,000 tons, or 30 per cent of the production of the entire field. Of 52,365 m. drilled in the field during the year, 12,086 m. were drilled by Unirea—in the neighborhood of 23 per cent. At the end of the year 107 old wells in the district were producing; 12 wells were drilling and 4 wells were being worked over.

Gura Ocnitei.—This district, which has occupied the first place as a producer for the last three years, dropped to second place in 1940. The production reached 1,118,000 tons—a decline of 161,000 tons from 1939, or 12 per cent.

Twelve wells reached the producing horizons during the year, making a total of 325 producing wells, while nine were drilling at the close of the year. The completed wells were allocated as follows: Concordia, 7; Prahova, 3; Unirea, 1; Foraky Romaneasca, 1.

The biggest producer was Concordia, with 140 wells and a total production of 542,000 tons; the second was Prahova, with 70 wells and a production of 210,000 tons.

Of the 12 wells drilled, only 3 were drilled to the Dacien, compared with 10 the previous year. The two best wells completed were Prahova 95, which was drilled to 1434 m. with an initial production of 57 tons, and Concordia 659, drilled to 2034 m. with a production of 33 tons.

Moreni.—Moreni continued in third place with 585,000 tons, in comparison with 710,700 in 1939, a decline of 20 per cent, or 125,700 tons. At the end of the year 236 wells were in production, 3 wells drilling and 11 working over. During the year, 15 wells were drilled, in contrast with 6 of the previous year. Wells drilled by companies were as follows: Creditul Minier, 8; Dacia Petroleum Syndicate, 1; Steaua Romana, 1; Unirea, 1; Foraky Romaneasca, 1; Continentala Petrolifera, 1; Petrolul Romanesc, 2. The total footage drilled was 12,000 m. Astra Romana was the largest producer, with 130,000 tons from 40 wells.

Ceptura.—Fourth in production was Ceptura, where 11 wells were drilled against 17 drilled in 1939. The total amount of drilling was 15,000 m., against 30,000 m. the previous year. Production reached 582,000 tons from 130 wells, in contrast with 694,000 tons of the previous year. Wells drilled by companies were as follows: Romano Americana, 7; Steaua Romana, 2; Astra Romana, 2. One well was drilling at the close of the year.

No special drilling difficulties were encountered; for instance, Romano Americana was drilled to 1520 m. in 31 days. In this field there is a pooling agreement between Astra Romana, Romano Americana, Steaua Romana and Creditul Minier.

Boldesti.—The production was 560,000 tons, against 694,000 tons in 1939. Drilling reached 17,000 m., against 16,600 m. the previous year. Eight wells were drilled, distributed as follows: Astra Romana, 5; Romano Americana, 2; Unirea, 1.

Piscuri.—Piscuri, which is an extension of Moreni, was explored by Romano Americana and Creditul Minier. Three wells were drilled to the Dacien and three to the Meotic. The production of the field totaled 352,000 tons, against 337,000 in 1939. Drilling total was 12,000 m., against 11,000 the previous year. Ten companies were producing from 112 wells at the end of the year.

Bucsani.—Drilling recommenced in this area, and Steaua Romana drilled 192 m. during the year. The production of 260,000 tons was won from 70 wells, compared with a production of 308,000 tons from 80 wells the previous year.

Ochuiri.—Astra Romana completed two wells in this field to depths of 1464 and 1428 m., respectively, for 10 tons production per day. At the close of the year

Prahova was drilling two wells and Petrolul Romanesc one. Production reached 252,000 tons from 87 wells, compared with 266,000 tons in 1939. I.R.D.P. occupied first place as a producer, with 50,000 tons.

Rasvad.—Only one well was completed in the Rasvad field (an extension of Moreni). No. 353 Steaua Romana produced 4 tons daily from 1851 m. At the close of the year, 37 wells were producing, of which 22 belonged to Astra Romana, which has 70 per cent of the production. Production for the year was 225,000 tons.

TABLE 4.—*General Statistics for the Rumanian Petroleum Industry for* 1939 *and* 1940

Item	1940	1939	Per Cent Change
Drilling, meters	241,500	256,000	− 5.7
Production of crude oil, metric tons	5,813,000	6,240,000	− 6.8
Treated in refineries, metric tons	5,469,500	5,837,000	− 6.3
Resultant product, metric tons	4,985,000	5,411,619	− 7.9
Internal consumption, metric tons	1,862,000	1,784,750	+ 4.3
Total exports, metric tons	3,493,500	4,177,571	− 16.4
Exports crude oil, metric tons	297,500	329,168	− 9.6
Exports via Constanza, metric tons	1,430,389	2,757,662	− 48.1
Exports via Giurgiu, metric tons	1,238,771	1,204,367	+ 2.9
Exports from other points, metric tons	824,332	215,542	+282.4

Margineni.—Production improved in this field, owing to the activity of Romano Americana, which drilled seven wells. Astra Romana drilled one well and Colombia one. Production was 135,000 tons, against 52,000 tons the previous year. Drilling totaled 24,000 m., in contrast with 17,000 m. in 1939. At the end of the year 18 wells were producing and 2 drilling. The depths of the wells completed ranged from 1870 to 2140 meters.

Chiciura-Bustenari-Bordeni.—Production from these old fields was 106,000 tons, in contrast to 118,000 tons of the previous year, obtained in the main from the operations of 80 small companies; 414 wells were producing, against 422 producing in 1939. Drilling was only 600 m., limited to workovers or deepening jobs in four wells.

Baicoi.—Production increased from 51,000 tons in 1939 to 91,000 tons in 1940. Romano Americana completed two wells, No. 271 to a depth of 2721 m. for 114 tons and No. 280 to a depth of 2625 m., with a production of 6 tons per day. At the close of the year 43 wells were producing and 2 drilling.

Runcu-Mislea.—Foraky Romanesca drilled No. 127 to 762 m. and Steaua Romana drilled wells 544 and 535 to depths of 1433 and 1123 m., respectively. The production of 77,000 tons came from 143 wells, in comparison with a production of 97,100 tons in the previous year from 137 wells. The production was mainly from the properties of numerous small companies.

Liliesti.—Owing to the activities of Romano Americana, Concordia, Colombia and Unirea, which in collaboration have drilled eight wells of great depth, production was increased from 55,000 tons in 1939 to 61,000 tons in 1940. Of the eight wells drilled, six reached depths in excess of 3000 m. and the other two approached this depth (No. 31 Concordia, 2926 m., and No. 36 Concordia, 2981 m.). At the end of the year, three additional wells were drilling—one by Concordia, one by Romano Americana and one by Unirea. The deepest wells in Rumania are in this field.

Teis-Aninoasa.—The production from this field was 40,000 tons from 14 wells, in contrast with 52,000 tons from 15 wells in 1939. The status of the wells in the field is as follows:

Company	Producing Wells	Drilling
Prahova	8	1
Petrolul Romanesca	3	1
Unirea	3	
	15	2

Bacau (Moldavie).—The fields of this department produced 43,000 tons in 1940 in contrast to 46,200 tons in 1939. This comes from 94 pits and 181 wells in the fields of Moinesti, Stanesti, Zemes, Solont, Tazlau and Lucacesti. About 1000 m. of drilling was done, 617 m. at Stanesti and Tazlau by Moldonaphta, and 297 m. at Comanesti by Petrolmina.

Arbanasi.—Production in Arbanasi was 37,000 tons, compared with 42,900 tons in 1939, from 85 productive wells worked by Steaua Romana, Colombia, Petrolul Romanesca and Romana Belgiana. Steaua Romana operated four pits at Sarata in the Department of Buzau.

Campina.—The production for the year was 28,000 tons from 63 wells, of which 58 belonged to Steaua Romana.

Aricesti.—Production in Aricesti was 19,000 tons from eight wells, of which seven belonged to Steaua Romana and one to Romano Americana. At the end of 1940, Romano Americana was drilling one well on the Sospiro lands.

Copaceni.—Production in Copaceni was 16,000 tons from the six wells of Naphta Romana, the same as in 1939; 500 m. was drilled during the year. Drilling of one well continues.

Viforata.—Production in Viforata continued to decline, being 16,000 tons in 1940, against 22,000 tons in 1939 and 39,000 in 1938. Thirteen wells were producing.

Draganeasa-Pitigaia.—Forage Lemoine has two wells in the Draganeasa-Pitigaia field, and produced 10,000 tons during the year and drilled 820 meters.

TABLE 5.—*Production and Drilling in Rumania for the Year* 1940

Field	Gross Production, Tons			Stocks Dec. 31	Drilling, Meters			Wells and Pits as of Dec. 31, 1940			
									Wells		
	Nov.	Dec.	Total 1940		Nov.	Dec.	Year 1940	Pits	Work Overs	Drilling	Production
Tintea	84,042	87,370	1,209,415	10,619	3,051	1,797	54,325		6	10	106
Liliesti	7,637	8,557	114,601		1,052	573	20,410		1	5	8
Baicoi	8,092	8,859	93,476	4,613	254	13	8,697			1	43
Margineni	7,588	4,746	124,632	1,379	989	2,953	25,841			1	12
Moreni	37,363	38,512	563,599	16,160	697	532	9,349			2	225
Piscuri	25,607	28,580	348,507	8,153	315	391	14,004		2	1	112
Ceptura	28,289	30,471	543,065	7,661	1,065	339	15,887				94
Boldesti	32,733	45,753	586,891	10,423	1,047	389	15,566			3	93
Aricesti	305	553	16,472	629							8
Runcu	6,249	6,778	82,936	3,561	54	17	4,030			1	137
Chicuira-Bustenari-, Bordeni	7,772	7,903	104,485	2,909	216		733	36	9	1	411
Campina	2,397	2,345	27,655	1,922							63
Pitigaia, Gura Dragenesei	350	300	10,160				821				2
Capaceni	1,154	1,205	15,848	2,749	82	51	884			1	6
Scaiosi	70	77	964	275							3
Maniesti					968	1,475	4,140			2	
Calugareni					537	208	769			1	
Vulcanesti					285	441	1,127			1	
Magurele							694				
Floresti							1,721		1		
Atarnati V Dulce						211	211			1	
Gura Ocnitei	81,899	81,780	1,093,978	16,338	2,684	2,656	32,005		1	10	318
Buscani	18,611	19,669	258,646	8,221			192				62
Ochuiri	17,466	17,772	245,424	6,293	2,178	2,309	13,174		2	5	80
Rasvad	20,034	20,567	236,470	5,877		3,177	6,365		1	1	42
Tels-Aninosa	2,923	2,938	38,838	1,365	751		5,196			1	14
Viforata	1,353	1,225	15,864	776							12
Glodeni	110	106	1,454	15							3
Doicesti					154		3,808			1	
Arabansi	2,859	2,952	36,581	2,030			209	4		1	85
District Bacau	3,469	3,534	43,039	3,537	65	197	1,352	103	1	4	86
Totals	398,372	419,502	5,813,000	292,869	16,448	17,729	241,500	143	24	54	2,125

Glodeni.—During the year, 1400 tons was produced from one well of Steaua Romana.

Scaiosi.—Production in this field was 1000 tons from two wells operated by Socop, controlled by Creditul Minier.

Exploration

Berca-Joseni.—Astra Romana drilled one well on a 400-hectare block to a depth of 2457 meters.

Magurele (Prahova).—Creditul Minier carried the No. 2 well started by Neo-Petrol to 531 m., where it was suspended in April; No. 3 was drilled to 2675 and produced salt water. The work of exploration in this area began in 1938, when at 2291 to 2296 ft. production was found, which yielded 1400 tons of emulsion of which 30 per cent was salt water.

Manesti (Prahova).—Steaua Romana, drilling for the account of Unirea, completed the No. 3 well to a depth of 2228 m. Unirea redrilled its No. 1 from 1928 m. to 2079. This brings the total of the wells in this field to six, of which five were completed before January 1940. These wells have established the presence of large deposits of gas in the Dacian and Meotic, which constitute important reserve of fuel for the towns of Ploesti and Bucharest. A new well was spudded in by Romano Americana on Aug. 5 at Manesti-Vladeni (No. 4), which in early December had reached a depth of 114 meters.

Doicesti (Dambovita).—Astra Romana drilled exploratory well No. 11 to 1689 m. and was still drilling No. 12 in December; it had reached 1853 meters.

Floresti.—Petrolul Romanesca drilled No. 50 to 1721 m., where it now stands suspended.

Vulcanesti.—Creditul Minier No. 1 was drilling at 975 m. at the close of the year.

Calugareni.—Creditul Minier No. 270 was drilling at 647 m. at the close of the year.

Comanesti.—Petrolmina's wildcat was drilling at 297 m. at the close of the year.

Tintea.—Concordia's wildcat at Tintea had reached a depth of 3338 m. at the close of the year and was drilling inside 6-in. casing.

TABLE 6.—*Operations of Refineries in Rumania*[1]

Year	Crude Oil Treated	Gasoline	Kerosene	Gas Oil	Fuel Oil	Other Products	Used as Fuel
1940	5,469,500	1,442,487	793,403	798,363	1,803,504	147,388	123,449
1939	5,849,423	1,556,905	968,438	770,221	1,953,981	152,074	91,000
1938	6,217,500	1,529,022	1,082,793	858,391	2,128,370	219,186	101,913
1937	6,656,564	1,588,512	1,112,893	993,063	2,331,104	175,132	268,620
1936	8,038,004	1,921,851	1,290,330	1,280,622	2,789,733	227,852	309,080

[1] All figures in metric tons.

Geophysical Prospecting was being carried on in the regions of Oltenie, Walachie and Moldavia by the large companies.

A.C.E.X., the Government organization for the coordination and orientation of mineral exploration, is carrying out explorations at this time with the necessary specialized personnel and has additional plans for the coming year.

Additional Statistics

Additional figures for the year 1940 showed declines in all fields of activity. No new fields were discovered and operations were of a routine nature, as would be expected from the political history of the year. Changes in the currents of international trade in petroleum products are shown in the decline of exports via the Black Sea port of Constanza, and the increase in the shipments through Giurgiu,

the Danube port, and by other ports, that is railroads, to central Europe.

TABLE 7.—*Stock of Crude Petroleum at Field and Pump Stations*

Companies	Tons of Crude Oil as of Dec. 31, 1941
Astra Romana	34,981
Concordia	53,871
Romana Americana	7,241
Steaua Romana	46,735
Colombia	20,721
Unirea	11,800
Prahova	2,020
Total	177,369

Tables 4 to 8 give the important statistics of the industry as reflected in the February number of *Moniteur du Pétrole Roumain.* At the time of writing, complete statistics for the export of petroleum products by the country were not available, but preliminary figures for the month of December indicate that exports to Germany and Italy had reached 244,998 tons per month, the largest portion of which went to Germany.

It is doubtful whether the production of Rumania can be very much increased during the coming year, and the amount available for export will probably remain at about 3,500,000 tons.

TABLE 8.—*Activity of Petroleum Industry in Rumania*

Months, 1940	Drilling, Meters	Index, Jan. = 100	Production, Tons	Index, Jan. = 100	Treated Tons	Index, Jan. = 100	Exportation, Tons	Index, Jan. = 100	Exportation by Products Tons	Index, Jan. = 100	Domestic Consumption, Tons	Index, Jan. = 100
Jan.	10,216	100	515,341	100	489,446	100	5,719	100	302,130	100	195,649	100
Feb.	19,099	187	488,507	95	504,187	103	11,877	208	205,313	68	206,406	105
Mar.	21,759	213	520,672	101	471,978	96	14,132	247	284,336	94	180,556	92
Apr.	23,682	232	501,109	97	445,902	91	31,658	554	231,075	76	147,994	76
May	22,728	222	519,617	101	526,546	108	59,551	1,041	428,282	142	159,866	82
June	21,063	206	499,338	97	484,071	99	15,059	263	207,516	69	140,755	72
July	20,615	202	517,478	100	472,472	96	40,068	701	285,972	95	139,578	69
Aug.	29,931	293	524,030	102	435,185	89	32,706	572	288,190	95	121,939	62
Sept.	18,312	179	441,112	86	418,069	85	10,006	175	246,354	82	128,997	66
Oct.	19,922	173	467,922	81	439,260	90	19,953	349	295,735	98	156,878	74
Nov.	16,444	161	398,372	76	372,916	76	32,556	385	240,306	80	134,831	69
Dec.	17,729	174	419,502	81	409,468	84	24,128	422	180,870	57	148,551	76
Total 1940	241,500	73	5,813,000	67	5,469,500	68	297,413	47	3,196,079	51	1,862,000	120
Total 1939	256,000	78	6,240,000	72	5,837,000	73	329,168	52	3,848,403	62	1,784,750	115
Total 1938	288,000	88	6,610,000	76	6,217,500	77	335,437	53	4,159,325	66	1,674,046	108
Total 1937	394,500	120	7,153,000	82	6,656,000	83	472,402	75	5,195,935	83	1,620,678	105
Total 1936	329,000	100	8,704,000	100	8,043,000	100	628,585	100	6,256,131	100	1,545,603	100

Russian Oil Industry in 1940

By Basil B. Zavoico,* Member A.I.M.E.

Production of crude oil in the U.S.S.R. during 1940 is estimated at 222,600,000 bbl., as compared with the revised figure for the preceding year of 220,866,000 bbl., an increase of 0.79 per cent, and at least 20 per cent under the planned output. Baku district (Transcaucasus) remained the outstanding producing area, accounting for 72.33 per cent of the country's production, and this relative importance of the Apsheron Peninsula oil fields will probably continue for many years to come.

In the North Caucasus the Grozny-Dagestan area further extended its decline and the current production in this district amounts to only 6.06 per cent of the total U.S.S.R. output, as compared with 35.76 per cent in 1931. The production of the Kuban-Maikop district remained virtually unchanged from the preceding year, amounting to 7.64 per cent of the country's total. The Caucasian Province, therefore, in 1940 produced 86.03 per cent of the total production of the U.S.S.R. The promising new Permian Basin district, called Ural-Volga, and referred to sometimes as the "Second Baku," increased its production appreciably during 1940 and the output of that area amounted to 8.31 per cent of the country's total, as compared with 6.35 per cent during 1939.

Production in the secondary districts of Russia continued unchanged though some new discoveries in the Emba salt-dome basin suggest that the output of that district may show some increase during the coming years.

The drilling operations in Russia during 1940 reached a stage of virtual breakdown and the original footage plans were fulfilled only to the extent of around 50 per cent, while exploration drilling schedules were fulfilled only to the extent of about 25 to 35 per cent. This condition was due to the obvious lack of modern drilling rigs, of good drill pipe and of strong casing. Extended breakdowns occurred with deeper drilling, particularly because with few good drilling rigs available speed was being attempted with rotation rates that the inferior drill pipe and bits could not stand. Twistoffs and endless fishing jobs resulted. The difficulties became so serious a handicap to the Soviet oil industry that it was found imperative to order American drilling equipment and pipe in quantity, a policy that was never favored in the U.S.S.R. because it requires expenditure of gold or exchange in major volume, and such exchange usually is reserved only to less bulky key items or to orders directly connected with armaments; also, oil-field machinery is very bulky and the prevailing lack of bottoms makes the transport of the indicated equipment a major problem.

But little progress was similarly made in other branches of the Soviet oil industry. No new major pipe-line construction work was undertaken, consequently the railroads continued to be overburdened with traffic that could be much more effectively handled by pipe lines. No new refinery construction of any magnitude was initiated, though several plants that had been in course of construction for several years were completed during 1940 and operation

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TABLE 1.—*Production of Crude Oil in Russian Fields,* 1931 *through* 1940

Year	Total U.S.S.R.,[1] TB[2]	Caucasus										Ural-Volga, Total, F[3] = 7.19		All Others									
		Total		Transcaucasus, F[3] = 7.28		North Caucasus								Total		Emba, F[3] = 6.97		Central Asia				Sakhalin, F[3] = 6.82	
						Total		Grozny-Dagestan, F[3] = 7.19		Kuban, F[3] = 7.33								Turkmen, F[3] = 7.41		Sredazneft, F[3] = 7.20			
		TB	Per Cent[7]	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent	TB	Per Cent
1931	162,146	158,273	97.61	96,229	59.35	62,044	38.26	57,979	35.76	4,065	2.51	43	0.03	3,829	2.36	2,270	1.40	103	0.06	544	0.34	912	0.56
1932	155,078	151,340	97.59	89,089	57.45	62,251	40.14	55,433	35.75	6,818	4.40	75	0.05	3,663	2.36	1,722	1.11	251	0.16	443	0.29	1,247	0.80
1933	155,836	151,379	97.14	111,965	71.85	39,414	25.29	34,959	22.42	4,455	2.86	248	0.16	4,208	2.70	1,369	0.88	1,146	0.74	354	0.23	1,339	0.86
1934	175,727	171,315	97.49	140,088	79.72	31,227	17.77	24,232	13.79	6,995	3.98	535	0.30	3,877	2.21	1,684	0.96	119	0.07	425	0.24	1,649	0.94
1935	182,967	172,807	94.45	141,258	77.20	31,549	17.24	22,793	12.46	8,756	4.79	2,978	1.63	7,188	3.93	1,913	1.05	2,488	1.36	1,155	0.63	1,632	0.89
1936	202,544	187,450	92.55	158,300	78.16	29,150	14.39	21,500	10.61	7,650	3.78	6,844	3.38	8,250	4.07	2,100	1.04	2,850	1.41	1,200	0.59	2,100	1.04
1937	204,150	186,592	91.40	155,792	76.31	30,800	15.09	20,800	10.19	10,000	4.90	7,101	3.48	10,457	5.12	2,900	1.42	3,470	1.70	1,387	0.70	2,700	1.32
1938	219,194	197,494	90.10	161,108	73.50	36,386	16.60	19,236	8.78	17,150	7.82	9,425	4.30	12,275	5.60	3,325	1.52	4,000	1.82	1,600	0.73	3,350	1.53
1939	220,866	194,500	88.06	161,500	73.12	33,000	14.94	15,500	7.02	17,500	7.92	14,016	6.35	12,350	5.59	3,500	1.58	4,000	1.81	1,600	0.72	3,250	1.47
1940	222,600	191,500	86.03	161,000	72.33	30,500	13.70	13,500	6.06	17,000	7.64	18,500	8.31	12,600	5.66	3,750	1.68	4,000	1.80	1,600	0.72	3,250	1.46
1941[4]	230,350	195,000	84.65	165,000	71.63	30,000	13.02	12,500	5.43	17,500	7.60	22,500	9.77	12,850	5.58	4,000	1.74	4,000	1.74	1,600	0.69	3,250	1.41
1941[5]	350,759	257,040		196,560		60,480		29,479		31,001		50,330		43,389									
1942[4]	249,000	200,000	80.32	170,000	68.27	30,000	12.05	12,000	4.82	18,000	7.23	35,000	14.06	14,000	5.62	4,500	1.81	4,250	1.71	1,750	0.70	3,500	1.41
1942[6]	342,000	255,474		184,680		70,794						50,274		36,252									

[1] Refer to Petroleum Development and Technology, *Trans.* A.I.M.E. (1937) **123,** 619, for production figures prior to 1931.
[2] TB indicates thousands of barrels.
[3] F indicates conversion factor from metric tons into barrels, from average crude gravities in each district.
[4] Author's estimate.
[5] According to Soviet plan of 1938.
[6] According to Soviet plan of 1940.
[7] All percentages calculated to total U.S.S.R. production.

of some additional units is planned for 1941. The hope of using natural gas for industrial fuel and for public utility purposes was still far from realization; and even though several major gas reserves are known to exist in the territory of the U.S.S.R. there is not a single city in the country except those in the immediate vicinity of the oil fields that is now being served by natural gas.

Russian crude-oil production (Table 1) has remained virtually unchanged since 1936, in which year it reached 202,544,000 bbl. The indicated stabilized production superimposed upon the rapidly expanding industrial economy of the U.S.S.R. could not but exercise a delaying influence upon the growth of industrial Russia, particularly while faced with the rapidly mounting requirements for the military establishment, which, more specifically, is reported to include a vast air force and large tank and motorized corps, all requiring large volumes of the best grades of fuels.

Production

Transcaucasus.—The fields of the Apsheron Peninsula (Baku district) continued to maintain their production principally because of the development of additional flush production in the newer oil fields in the district west from Baku on the Lok-Batan-Binagadi trend. In this area Chakhnagliar field proved to be particularly prolific and served largely to counterbalance the declining production of other fields of the district. In the older fields of the Baku area development of the deeper sub-Kirmaku sands continued actively and also a number of pools were somewhat extended during the year. On the whole, however, the main policy of the Baku Trust remained unchanged, the maintenance and increase in production being counted upon to be derived primarily from the naturally flowing wells; hence, if during a relatively short period, say one-half year, exploration activities are not successful in finding and in developing new flush reserves, production of the Baku district may decline 25 to 30 per cent in a period of time as short as 2 years, and such decline probably will have a catastrophic effect on the transportation services of the country and on manufactures that use fuel oil exclusively.

North Caucasus.—The older pools in the Grozny area continued their decline, begun in 1931. In that year, this district produced 57,979,000 bbl. while the fields then productive produced in 1940 probably not over 5,000,000 bbl. A new and important field apparently was discovered during 1940 east of the New Grozny field at Oisungur, where exploration started in 1926, was discounted in 1928 and again resumed in 1938, the discovery well being completed for 2100 bbl. from 4900 ft. This apparently important discovery is 35 miles due east from Grozny and in the central portion of the Gudermes Range, which is one of the major structural trends of the area, parallel and in echelon with Terski and Sunjenski Ranges, upon which have been located the older fields of this district. However important Oisungur may appear, probably it is located too far from the service centers to be quickly assimilated by the Soviet management and it is to be doubted that the production from the Grozny district of the North Caucasus will show appreciable increase in the coming few years. The Grozny district continued to suffer from the already indicated policies of the Soviet management to draw primarily from the naturally flowing wells at capacity, disregarding production from smaller wells from which it must be lifted mechanically. Thus, in some of the major fields of the Grozny district as much as 70 per cent of the total number of productive wells was on the shutdown list, because of lack of compressors, deep pumps, or repair parts for that equipment. It was also of interest to learn during the past year that the light oil from the Gorski field was being stored in

open pits, from which evaporation losses would be great.

In Kuban district production has become more or less stabilized at around 17,000,000 bbl. per year, after reaching that level in 1938, when it rose sharply from a production rate of about 10,000,000 bbl. per year. Difficulties facing Baku and Grozny district were encountered in the Kuban area also, causing rapid decline of the flush wells where adequate equipment was lacking for handling the wells that discontinued natural flow. No new discoveries of consequence were made in this region during the year.

Ural-Volga Permian Basin.—The Ural-Volga Permian Basin, comprising the immense territory from Perm to the Caspian Sea, continued to increase its output during 1940, its production reaching 18,500,000 bbl. as compared with 14,016,000 bbl. in the preceding year; and further large increases are anticipated in the coming years. The most important development in this basin took place in the Buguruslan area, in which production is found at between 800 and 1000 ft. in the Permian limestones, with initial production of the wells ranging from 350 to 700 bbl. per day. A large area has been proved for production in the Buguruslan district in which extensive drilling operations will be conducted during 1941. However, in this area spacing patterns are entirely too close for this type of production—one well to 4 acres—hence a large amount of unnecessary drilling will take place and the number of wells completed will not be the true measure of the reserves developed, if considered on the basis of production in the West Texas Permian Basin in the United States. At Tuimazi, between Buguruslan and Ishimbaevo, Devonian limestones were found to carry apparently commercial oil saturation though no production has been developed as yet. The first well that tested Devonian in the Tuimazi area has found igneous formations at about 5700 ft., which is considerably higher than the basement complex expected in this territory. Devonian was encountered also near Ishimbaevo itself, on the Shihani anticline, where porous, saturated dolomites of the Upper Devonian were found. The discovery well was thought to be able to produce 350 bbl. per day from around 35 ft. of oil-bearing section. Elsewhere in the Permian Basin and to the west of it a number of exploration wells showed promising results but because of the slowness of the Soviet exploration tactics and exaggeration of the first reports, it is impossible as yet to judge what really has been found.

In the Sizran area of Samarski Luki, further exploration work continued, as well as did the development of already proven fields, but the results on the whole were most unsatisfactory, principally because of ineffective drilling operations. In this area also commercial Devonian oil saturation has been proved, though not developed; hence sediments of that age apparently will form a very important source of oil in the future and not only in the Ural-Volga Permian Basin but also possibly farther west in the Moscow Basin.

Emba District.—The production of the Emba district continued at about the unchanged rate from the preceding year but new discoveries made during last year on the salt dome known for some time are expected to result in slowly increasing output from this secondary area upon which the Soviet geologists have always placed too much hope. An interesting reinterpretation of the former geophysical work in the light of actual drilling is that many of the adjacent salt masses are not really individual salt domes but large single domes extensively faulted. The presence of such large domes very extensively block-faulted makes search for flank production difficult.

Exploration

Exploration for oil and natural gas outside of the districts mentioned has been

none too successful; in many instances the good work of the geologists being counteracted by the impossibility to test the areas effectively by drill resulting from the general breakdown of the drilling operations in the country. Thus, the salt-dome basin of the Ukraina still remains in the nebulous stage of development, no commercial production having been found as yet. Similarly, really promising fields in Georgia, in Transcaucasus, still are accounting for less than 1000 bbl. per day, though their reserves and location should have resulted in much larger output by this time. Also, exploration of the very promising territory of the northwest shores of the Caspian Sea between the Grozny district and the Emba salt-dome province remains only in preliminary stages, as does also the work in the immense sedimentary basin due east from the Ural Mountains. Exploration work and drilling in Siberia are being conducted in several locations but with mediocre results. No commercial production from that territory can be anticipated in the near future, though geologically the area must be considered most favorable. In Turkmen area and in Turkestan, as well as in Sakhalin, only routine operations took place. There were no major discoveries or appreciable changes in the production.

Drilling

As already indicated, drilling constituted the primary stumbling block to the more rapid development of the oil industry in the Soviet Union. Many reasons have been responsible for the breakdown but more specifically poor quality of drilling equipment, of drill pipe, and of casing, superimposed upon inexperienced labor, have caused such extensive breakdowns at the greater depths and faster speeds that not over one-half the program has been fulfilled in the whole country and locally operations have been actually at a standstill. Furthermore, completion of the drilling footage programs even to the extent of 50 per cent does not reveal the whole picture, as has been suggested in a number of instances in the Soviet technical press. Actual cases have been cited of drilling programs fulfilled to the extent of 60 to 70 per cent as far as the footage is concerned, but none of them ending in the successful completion of oil wells; therefore the expression of the completion of the plans in footage does not really represent a true picture, since, as indicated above, the figures are often zero.

To correct the difficulties, portable rigs capable of drilling to around 4000 ft. have been ordered in the United States for shipment across the Pacific, the total number possibly reaching 200.

With the breakdown of the rotary-drilling operations, caused largely by the poor quality of the drill pipe, the attention of the Soviet engineers and management was attracted to the turbine and electrical methods, in which the motive power is located at the bottom of the well and the drill pipe remains stationary, thereby eliminating the danger of the twistoffs. Turbine drilling is already in a considerably advanced stage and a number of rigs are in operation, some wells having been drilled to as much as 8500 ft., but here again the lack of special equipment and the necessity of having high-pressure equipment are not conducive to rapid progress. The newer electrical drilling method, with the motor at the bottom of the well and not requiring high-pressure equipment, is still in its earliest stages of development; only one rig is in operation, therefore results to date are nonconclusive. It should be noted again, however, that both these methods are attracting attention in Soviet Russia because of the poor quality of the domestic equipment, which cannot stand the punishment of the present high-pressure rotary-drilling operations.

Conclusions

The Russian oil industry is still working under the almost insurmountable handicap

of having to supply a rapidly expanding national economy from an insufficiently developed reserve. In a country with backward engineering technique, not only a huge waste is entailed of both crude oil and natural gas but also the flush production can and probably will be pyramided to a point from which it may drop sharply. Table 1 shows planned production for 1941 and 1942 together with the author's estimates for those years. It is needless to say that while the country could well absorb 350,000,000 bbl. in 1941 and the same amount in 1942, as stipulated in the various plans, such rate of production is entirely out of reach under present management and policies. It should be noted particularly that the current rate of production is some 33.3 per cent under the plans made in 1938, and that in all probability such an undersupply is beginning seriously to affect civilian phases of motor-fuel consumption, and apparently is putting an additional burden upon the coal industry. These developments explain readily the recent trend in many parts of Russia to build and use vehicles driven by such inefficient substitute fuels as alcohols, charcoal or wood.

Petroleum Developments in Venezuela during 1940

By D. C. Porterfield*

As a result of world economic conditions brought about by the European war and the consequent loss of European markets for Venezuelan crude, production in Venezuela decreased from 205,433,000 bbl. in 1939 to 186,134,000 bbl. in 1940, or 9.4 per cent. This decline interrupted a steady annual increase in production from the country, which had been continuous since 1932. The Maracaibo Lake Basin in western Venezuela accounted for 135,738,000 bbl. during 1940, or 73 per cent of the total, as against eastern Venezuela's production of 50,396,000 bbl., or 27 per cent of the total for the country. Corresponding figures for 1939 were 167,688,000 bbl., or 82 per cent of the total from the Lake Basin, and 37,744,000 bbl., or 18 per cent from the east. These comparisons indicate the increasing importance of the newer developments in eastern Venezuela, but it is unlikely that production from the east will ever exceed that from the west.

In all, 429 new wells were completed in Venezuela during 1940 as compared to 438 in 1939. Of the 1940 completions, 411 were in proved areas and 18 were wildcats; 389 (95 per cent) of the exploitation wells drilled were producers, 1 was a gas well and 21 were dry holes, while 6 (33 per cent) of the wildcats drilled were producers and 12 (67 per cent) were dry; 263 of the exploitation wells and 4 of the wildcats were in the Maracaibo Lake Basin and 148 exploitation wells and 14 wildcats were in the east, mostly in the State of Anzoategui.

Exploration of the light-oil areas in the Tia Juana and Lagunillas fields was continued during the year with favorable results. Along the lake shore, drilling was confined principally to fill-in wells in the La Rosa, Tia Juana, Lagunillas and Bachaquero fields, although some important semi-exploratory drilling was done in the Pueblo Viejo area between Lagunillas and Bachaquero fields.

The only other developments of particular interest in the west were the successful completion of a step-out well lying to the south of the former southern limit of Mene Grande field, which adds considerable proved acreage to that field; and the failure of two wildcats that were drilled near the Colombian border to determine whether the productive sands of the Petrolea field in the Barco Concession, Colombia, extend into Venezuelan territory.

In the east no new fields were discovered during the year, although five wildcats were completed as producers. Three of these, Guario No. 1, Jusepin-56 and LM-1 (Leona), discovered important extensions to previously proved areas and the remaining two, Caritos-1 and SPN-1 (Socororo), were subsequently proved to have tapped productive sands of small extent and operations in these areas have been suspended.

The greatest activity in the east was concentrated in the Oficina field, where 105 new wells were completed during the year and production was increased from 22,540 bbl. per day during January 1940 to 57,627 bbl. per day during December 1940.

Important development work was also done in the Jusepin, San Joaquin and El Roble fields.

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TABLE 1.—*Oil and Gas Production in Venezuela*

Line Number	Field	Year of Discovery	Area Proved, Acres	Total Oil Production, Bbl.	
			Oil[b]	To End of 1940	During 1940
1	La Rosa/Punta Benitez	1922	35,488	384,130,887	19,324,559
2	Tia Juana	1928	24,026	155,247,495	36,946,186
3	Lagunillas	1926	54,884	947,139,080	58,464,785
4	Bachaquero	1930	25,627	6,055,923	1,682,959
5	Total Lake fields		140,025	1,492,573,385	116,418,489
6	Concepción	1925	1,200	21,780,619	838,967
7	Cumarebo	1931	547	26,153,197	1,630,785
8	El Mene	1920	857	22,006,262	287,600
9	El Mene de Acosta	1927	75	790,114	0
10	Guanoco	1912	219	1,858,400	0
11	Hombre Pintado	1927	288	1,515,564	658,093
12	Jusepin	1938	5,684	4,511,270	3,995,154
13	La Paz	1922	350	5,674,526	449,232
14	Las Palmas	1928	50	348,619	42,461
15	Los Manueles	1927	600	20,574,079	2,612,510
16	Media	1929	244	2,596,392	34,203
17	Mene Grande	1914	6,650	220,363,025	10,812,402
18	Oficina	1937	9,775	17,956,725	15,414,106
19	Orocual	1933	2,100	29,528	0
20	Pedernales	1933	972	7,178,142	1,795,888
21	Quiriquire	1928	10,092	172,255,873	21,676,451
22	Rio de Oro	1915	332	54,877	0
23	Roble	1939	4,815	656,204	654,379
24	San Joaquin	1939	8,585	1,139,285	1,097,562
25	Santa Ana	1936	6,869	111,208	75,790
26	Tarra	1916	1,400	41,747,411	3,584,359
27	Temblador	1936	4,594	10,000,875	3,994,215
28	Totumo	1914	741	149,452	0
29	Uracoa	1937	2,060	41,467	876
30	Wildcat fields: Amana, Caritos, Guario, Leona, Los Barrosos, Lapa, Mamón, Merey, Areo, Misoa, Monte Claro, Netick, Pilón, Socororo, Yopales		27,856	593,729	60,868
31	Total		236,980	2,072,660,228	186,134,390

[b] Footnotes to column heads and explanation of symbols are given on page 256.

TABLE I.—(*Continued*)

Line Number	Total Gas Production, Millions Cu. Ft.: To End of 1940	Total Gas Production, Millions Cu. Ft.: During 1940	Number of Oil and/or Gas Wells: Completed to End of 1940	During 1940: Completed	During 1940: Abandoned	End of 1940: Temporarily Shut Down	End of 1940: Producing Oil[c]	End of 1940: Producing Gas[c]	Oil-production Methods, End of 1940, Number of Wells: Flowing	Oil-production Methods, End of 1940, Number of Wells: Artificial Lift	Reservoir Pressure, Lb. per Sq. In.: Initial	Reservoir Pressure, Lb. per Sq. In.: Avg. at End of 1940	Repressuring Operation[d]	Character of Oil: Gravity A.P.I. at 60°F., Weighted Average	Character of Oil: Sulphur, Per Cent
1			1,311	49	4	517	673	0	82	591	1,5xx	x	RP	24	1.8
2			531	28	1	177	352	0	92	260	1,2xx	x		18	2.1
3			1,425	101	2	573	776	0	122	654	1,5xx	x		17	2.1
4			77	38	0	63	14	0	14	0	1,6xx	x		15	2.5
5	x	80,xxx	3,344	216	7	1,330	1,815	0	310	1,505					
6	x	692	108	4	0	72	34	0	2	32	x	x		35	y
7	14,734	1,123	118	1	0	68	36	0	22	14	625	x	PM	49	0.1
8	x	x	286	0	0	y	y	y	y	y	500	x		33	
9	x	0	81	0	0	74	0	0	0	0	x	x		45	
10	x	0	24	0	0	14	0	0	0	0	x	x		11	
11	x	x	37	10	1	y	y	y	y	y	x	x		27	
12	3,521	3,237	57	36	0	34	22	0	22	0	2,575	x		32	0.9
13	x	414	33	0	0	17	12	0	0	12	x	x		23	y
14	x	x	13	0	0	6	3	0	0	3	x	x		32	0.2
15	x	1,458	25	2	0	8	15	0	15	0	x	x		31	
16	x	x	38	0	0	y	y	y	y	y	700			41	
17	x	6,481	432	26	0	234	175	0	44	131	x	x		21	y
18	20,367	18,167	144	105	13	19	107	2	107	2	1,834	1,528		31	1.1
19	x	0	7	0	0	3	0	0	0	0	x	x		13	
20	5,083	1,267	19	0	0	5	10	0	10	0	3,200	x		21	2.9
21	53,518	9,447	296	0	0	140	141	0	118	23	1,260	x	RP	19	1.2
22	x	0	4	0	0	3	0	0	0	0	x	x		27	y
23	1,875	1,875	2	1	0	0	2	0	2	0	x	x		45	0.1
24	x	1,510	10	6	0	0	10	0	10	0	x	x		42	0.1
25	4,166	2,197	2	1	0	1	0	1	2	0	x	x		53	0.1
26	x	1,608	104	5	0	30	61	0	7	54	x	x		28	y
27	2,917	1,017	90	1	1	18	57	0	57	0	1,665	x		22	1.0
28	x	0	12	0	0	4	0	0	0	0	x	x		20	2.2
29	x	x	2	0	0	2	0	0	0	0	x	x		16	1.5
30															
31			5,326	420	24										

TABLE 1.—(*Continued*)

Line Number	Producing Formation								Deepest Zone Tested to End of 1940	
	Name	Age[e]	Character[f,1]	Porosity[g]	Depth, Avg. Ft.		Net Thickness, Avg. Ft.	Structure[h]	Name	Depth of Hole, Ft.
					Top Prod. Zone	Bottoms Prod. Wells				
1	La Rosa series, Icotea, Eocene	Mio, Olig, Eoc	Ss, H	Por	900–2,500	2,500	80–350	MFU	Eoc	8,747
2	La Rosa series, Icotea, Eocene	Mio, Olig, Eoc	Ss, H	Por	1,600–3,700	2,600	100–350	MFU	Eoc	4,383
3	La Rosa series, Icotea, Eocene	Mio, Olig, Eoc	Ss, H	Por	2,100–5,300	3,400	80–550	MFU	Eoc	5,402
4	La Rosa series, Icotea, Eocene	Mio, Olig, Eoc	Ss, H	Por	2,850–4,300	3,900	75–450	MFU	Eoc	5,152
5										
6	Ramillete and Punta Gorda	Eoc	Ss, H	Por	950–3,800		200	AF	Eoc	5,786
7	Damsite and Socororo	Mio	S, H	Por	600–1,400	1,700	50	AF	Mio	7,720
8	Agua Clara	Olig	S, H	Por	950	1,135	50	A	Eoc	5,576
9	Cerro Pelado	Mio	S	Por	730	1,400	35	M	Eoc	4,994
10	Guanoco shale	CreU	H	Fis	1,200	1,300	40	AF	Cre	4,247
11	Agua Clara and San Luis	Mio, Olig	S, H	Por	700–2,300	2,100	200	AF	Eoc	4,614
12	La Pica	Mio	S, H	Por	4,000	4,670		AM		5,636
13	La Paz series	Eoc	S, LS	Por	400–1,400	1,355	125	AF	Cre	2,290
14	Agua Clara and San Luis	Mio, Olig	S, H	Por	2,600	2,620	x	AF	Eoc	5,xxx
15	Sandy shale, Mirador, Third Coal	Mio, Eoc	S, H	Por	3,475–4,150	4,120	400	AF	Eoc	6,260
16	Agua Clara	Olig	S, H	Por	2,200	3,565	200	AF	Eoc	5,285
17	U. La Rosa, Pauji and Misca	Mio, Eoc	S, H	Por	400–4,700	2,750	800	AF	Eoc	9,071
18	Oficina	Mio	S, H	Por	4,000	6,100	10–100	MF	Cre	6,966
19	Llanos and U. Miocene	Pli, Pleis, MioU	Ss	Por	2,700	3,560		MU	Mio-Olig	5,021
20	Pedernales	Mio	Ss	Por	5,000	5,200		A	Mio	7,853
21	Llanos and U. Miocene	Pli, Pleis, MioU	Ss	Por	2,000	2,980		MULC	Mio-Olig	8,285
22	Third Coal	Eoc	S	Por	1,350	3,020	60	A	Eoc	3,105
23	Oficina	Mio	Ss, H	Por	8,100–9,800	9,815		TF	Eoc	10,028
24	Oficina	Mio	Ss, H	Por	3,800–9,100	6,900		AF	Eoc	10,124
25	Oficina and Periquito, Sandy shale, Third Coal	Mio, Eoc(?)	S, H	8–15%	6,500	8,900	200–400	A	Eoc (?)	8,988
26	Mirador, Colon shale	Mio to CreU	S, H	Por	1,200	2,700	800	AF	Cre	8,793
27	Oficina	Mio	Ss, H	Por	3,860	3,870	40	MF	Mio-Olig	5,492
28	Totumo horizon	Pre-Mio	Brecc.	Fis	2,200	2,230	x	MF	Pre-Mio	2,4xx
29	Oficina	Mio	Ign, S, H	Por	4,200	4,330		MF	Mio-Olig	5,061
30										

[1] Ss indicates soft sandstone.

TABLE 2.—*Summary of Drilling Operations in Venezuela*

Important Wildcats Drilled in 1940

	State	Coordinates			Total Depth, Ft.
		North	East	Origin	
1	Anzoategui	176,186	589,680	Barcelona	7,815
2	Anzoategui	196,292	280,944	Sta. Maria de Ipire	7,155
3	Anzoategui	195,980	280,402	Sta. Maria de Ipire	4,070
4	Anzoategui	217,323	523,236	Barcelona	8,297
5	Anzoategui	152,936	497,026	Barcelona	6,939
6	Anzoategui	155,329	542,179	Barcelona	6,208
7	Guarico	272,619	657,636	Calabozo	3,276
8	Guarico	115,119	421,557	Barcelona	2,895
9	Guarico	121,650	422,129	Barcelona	3,385
10	Monagas	130,650	293,642	Maturin	7,098
11	Monagas	131,402	293,240	Maturin	5,985
12	Monagas	202,890	169,628	Maturin	5,412
13	Isla Cubagua				4,670
14	Isla Cubagua				5,155
15	Zulia	S28,211	E53,339	Maracaibo	8,810
16	Zulia	S233,828	W100,586	Maracaibo	2,563
17	Zulia	S233,885	W100,880	Maracaibo	1,718
18	Zulia	S100,664	E76,384	Maracaibo	9,071

Important Wildcats Drilled in 1940

	Drilled by	Initial Production per Day		Choke or Bean, Fractions of an Inch	Pressure, Lb. per Sq. In.		Remarks
		Oil, U. S. Bbl.	Gas, Millions Cu. Ft.		Casing	Tubing	
1	Mene Grande Oil Co.	1,330	0.838	$^7/_{16}$	760	740	LM-1 (Leona)
2	Standard Oil Co. of Venezuela	116		$^1/_4$	1,300	1,160	SPN-1 (Socororo)
3	Standard Oil Co. of Venezuela	Abandoned—dry hole					SSN-1 (Socororo)
4	Socony Vacuum Oil Co.	1,023		$^5/_{16}$		1,640	Guario-1
5	Socony Vacuum Oil Co.	Abandoned—dry hole					Pariaguan-1
6	Mene Grande Oil Co.	Abandoned—dry hole					OS-10 (Oficina)
7	Standard Oil Co. of Venezuela	Abandoned—dry hole					Gorrin-1
8	Mene Grande Oil Co.	Abandoned—dry hole					Tres Matas-1
9	Mene Grande Oil Co.	Abandoned—dry hole					Tres Matas-2
10	Texas	400		$^5/_{16}$	250	500	Caritos-1
11	Texas	Abandoned—dry hole					Caritos-2
12	Standard Oil Co. of Venezuela	260		$^3/_{16}$	1,050	525	J-56 (Jusepin)
13	C. A. Yacimientos Petroliferos en Cubagua	Abandoned—dry hole					Cubagua-1
14	C. A. Yacimientos Petroliferos en Cubagua	Abandoned—dry hole					Cubagua-2
15	Venezuela Oil Co.	Abandoned—dry hole					Pica Pica-1
16	Colon Development Co.	Abandoned—dry hole					Redondo-1
17	Colon Development Co.	Abandoned—mechanical difficulties					Redondo-2
18	Caribbean Petr. Co.	1,583		Open line	490	$^{25}/_{35}$	MG-407 (Mene Grande)

	In Proven Fields	Wildcats
Number of wells drilling Dec. 31, 1940	31	11
Number of oil wells completed during 1940	389	6
Number of gas wells completed during 1940	1	
Number of dry holes completed during 1940	21	12

Exports

Exports of crude and products from Venezuela decreased from 198,307,000 bbl. in 1939 to 180,331,000 bbl. in 1940, or 9.1 per cent. Crude-oil shipments declined 16.5 per cent, from 189,711,000 bbl. in 1939 to 158,404,000 bbl. in 1940, while shipments of refined products increased 155 per cent, from 8,596,000 bbl. to 21,928,000 bbl., as a result of increased refinery capacity constructed during the latter part of 1939 and the early months of 1940.

Table 3.—*Capacities of Various Plants in Venezuela*

Location	Operated by	Daily Capacity, Bbl.
La Salina......	Cia. de Petroleo Lago	39,500
Caripito.......	Standard Oil Co. of Venezuela	31,500
San Lorenzo....	Caribbean Petroleum Co.	28,000
Cabimas.......	Mene Grande Oil Co.	1,800
Oficina.........	Mene Grande Oil Co.	170
El Mene.......	British Controlled Oilfields, Ltd.	150
Tarra..........	Colon Development Co.	175
		101,295

Refineries

Additions to existing refineries begun in 1939 and completed in 1940 brought the total throughput capacity for the country up to 101,295 bbl. of crude daily. Total crude refined in the country during 1940 was 26,945,000 bbl. as compared to 13,419,000 in 1939. Table 3 indicates the capacities of the various plants in Venezuela.

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Petroleum in Yugoslavia*

In the special number of the magazine *Oel und Kohle* (Oct. 22, 1940) dedicated to the petroleum industry of southeastern Europe, there appeared several articles relating to Yugoslavia.† In the first article the author calls attention to the fact that there are two fields in Yugoslavia that have been explored and exploited by more than 100 wells at variable depths during the last 50 years. These are on the Island of Mura, at the confluence of the Mura and the Drave. Additional exploration drilling in various other parts of the country has been without result, but certain ones of these explorations have revealed the existence of gas horizons that have some value, which are being used for industrial purposes. Table 1 shows the production of oil and gas between the years 1900 and 1939.

Table 1.—*Production of Oil and Gas in Yugoslavia*

Years	Oil, Tons	Years	Natural Gas, Cu. Meters	Years	Natural Gas, Cu. Meters
1900–1929	10,000	1923	507,000	1934	1,388,000
1930	277	1924	567,000	1935	1,401,000
1931	202	1925	691,000	1936	1,483,000
1932	289	1926	1,472,000	1937	1,841,000
1933	629	1927	1,732,000	1938	2,431,000
1934	324	1928	2,515,000	1939	2,628,000
1935	260	1929	4,700,000		
1936	137	1930	5,345,200		
1937	463	1931	6,376,153		
1938	1,091	1932	1,661,737		
1939	1,114	1933	959,574		

The number of wells drilled from 1884 to the present time was in the neighborhood of 200 and the total footage drilled was 65,000 m. up to July 1940. They may be divided roughly as follows: 12 wells in the region produce natural gas; 134 wells in the two old fields of the Island of Mura and about 20 wells for the exploration of the zone of the Flysch, in Bosnia. The depths of 50 of these wells was 100 to 200 m.; the depths of 50 wells on the Island of Mura ran from 200 to 500 m.; of 25 wells, 500 to 1000 m.; of 10 wells from 1000 to 2000 meters.

The deepest well drilling in Yugoslavia has reached 2000 m. In the Valley of Morave, in the region of Selnica, 100 km. south of Nish, there have been discovered asphalt-bearing limestones, which contain about 15 per cent asphalt and are associated with bituminous clays. Later, at Paclenica, important deposits of natural gas were found. A zone rich in gas and oil seepages runs through Pracec, Miklenska, Bujavica, etc. The author studied these regions from the point of view of stratigraphy and tectonics. The anticlines and gas-bearing domes are concentrated in two zones: the region of the Drave (Island of Mura) and the region of the Save, southeast of Zagreb, which contains the gas field in exploitation in the region of Bujavica.

A full description of the productive region of the Island of Mura has been given by Egon Bohm, a geologist, in the second article mentioned. This includes a history of the exploration and exploitation that took place under Hungarian rule in this region. The most important exploration was effected between 1884 and 1885 by Stavenov and Stinger, of Vienna. In 1927 work was done in the same region by Anton Raky, a well-known explorer who makes work of this kind his specialty.

* Translation from *Moniteur du Pétrole Roumain* (Jan. 1941).

† Dr. L. Sommermeier (Yaslo): Die erdolhoffigen Gebiete in Jugoslawien.

Dr. K. Egon Bohm, geologue: Das erdolvorkommen der Murinsel.

Ing. chimiste Petrunic Alexandar (Zagreb): Erdgasgewinnung und Verarbeitung in Kroatien.

Von Herbert Schoen (Wien): Jugoslawien als Erdolland vom rechtlichen Standpunkt ausgesehen.

According to the author, deposits of petroleum and natural gas have been discovered in the Dacien at various depths and in beds of the Paludine age, as well as at the base of the Poretien and in beds of the Valenciennien. A graph covering two years, 1937–1939, indicates annual productions of 478,870 and 726 tons, respectively.

The gas deposits of Croatia were studied by an analytical chemist, Petrunic Alexander. These deposits are grouped in two important regions: (1) Bujavica in the district of Pakrac and (2) Goilo, in the district of Cutina. Concessions on the two regions were granted in 1929 to the Uljanik Company of Zagreb. The first exploratory well was started in 1918. In the region of Goilo the first well was started in 1930. The gas fields produced gas containing from 93 to 98 per cent methane with a calorific value of 8550 to 9520 cal. per cubic meter. The gas produced in the region of Bujavica was first utilized for lighting the railroad stations. For this purpose it was transported in a pipe line under pressure of 15 atmospheres and was served by a reservoir with an approximate capacity of 400 cu. m. In each of the stations small reservoirs were used for distribution of gas, which were maintained at a pressure of 6 atmospheres. At the beginning of 1928 the use of gas began in industry, and the works of the coal company at Bujavica consumed 10,000 cu. m. per day. In 1938 a modern factory for carbon black was installed at Cutina to utilize the gas from the deposits at Goilo. A project is under consideration for the construction of a pipe line to supply the town of Zagreb.

After 1935 methane was used in automobile motors. The gas was first compressed in iron cylinders of capacity of 40 liters containing 10 cu. m. of gas under pressures of 200 atm. The production of gas at Bujavica during the period 1935 to 1939 is shown in Table 2.

TABLE 2.—*Production of Gas at Bujavica*

Year	Cubic Meters	Year	Cubic Meters
1935	1,401,100	1938	2,432,000
1936	1,600,000	1939	2,628,000
1937	1,840,000	1940	3,000,000

The last article, by Herbert Schon, of Vienna, examines the juridical regime applicable to the petroleum and gas concessions in virtue of the mining laws of 1938. According to Article 3 of this law, the State is the sole proprietor of these deposits and they may be constituted a monopoly at the disposal of the State, which may consider concessions for their exploration and exploitation under conditions fixed by the law.

Chapter V. Education

Petroleum Engineering Education

By Harry H. Power,* Member A.I.M.E.

(Tulsa Meeting, October 1940 and New York Meeting, February 1941)

While the attention of all engineering branches is focused today on changes and improvements in the several curricula, we are concerned here with the many questions arising in industry and college concerning the preparation for the petroleum engineering profession. The succession of problems confronting the petroleum engineer demands a degree of versatility not ordinarily encountered in other professions. As a consequence, the student cannot acquire mastery of all the several engineering branches represented in field practice, and as an alternative, he has learned to appreciate the value of thorough training in the basic or fundamental sciences as a preliminary foundation for professional work.

While our attention is directed primarily to the training of engineers in educational institutions, it is necessary that the ultimate education of the professional engineer be kept in mind. It is apparent that his success as an engineer is limited not only by his educational and job experience, but by his native endowments: mentality, personality and health. The engineer's lack of job experiences often proves as much a handicap as the lack of adequate college training. If the final product proves to be satisfactory, both industry and technical institutions are to be congratulated. However, if the product is found wanting, the one most responsible should be apprehended.

Fitness for Profession

For the most part, students of engineering colleges have had their interests in applied science awakened at a relatively early age. Many of them entered college as a convenient means of acquiring a technical education, but undoubtedly would have had better prospects in a shorter program offered by institutions of non-college grade. The activating motive of practical interest is also strong in students suitable for college training, but in many cases an intellectual interest must be awakened in order that it may survive graduation.

Numerous engineers believe that this progressive process of selection and determination of career aims is one of the essential services rendered by the engineering colleges. Industrialists, who are more interested in quality than quantity of petroleum engineering graduates, have pointed out the good that should result if more emphasis were given to the work of eliminating the misfits. They also point out the protective measures that have been taken by other professions for the betterment of professional standards. Mention has been made of the beneficial results to be obtained by collective determination of the market for the products of engineering schools, particularly in that the students unsuited to the profession would have an opportunity to prepare themselves for employment more suited to their personalities and other qualifications. In the event that such a system of coordinated personnel direction is developed by the

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various institutions, more capable candidates would be properly guided and trained to fill positions of responsibility in operations, engineering departments, and research organizations. On the other hand, it has been noted that a danger does exist in limiting enrollments, since a regulated supply of graduates may have a tendency to establish a group of very independent individuals who lack the incentive to make a record of their own. A genuine desire to enter the petroleum engineering profession may, in some cases, be sufficient justification for accepting prospective students. However, it is obvious that certain criteria indicating the nonfitness of students exist, regardless of the apparent interest they may exhibit for the profession. Some of our engineering schools have gained enviable reputations by granting graduate degrees only to those who are capable of reflecting credit to the school, not only scientifically, but socially and politically as well.

Length of Course

It is obvious that the training of qualified students cannot be met properly by college programs of uniform length. Many educators are convinced that the terminal level reached at graduation and marked by the award of the usual bachelor's degree satisfies the interests and needs of many young men who seek to enter the technological pursuits. Graduation represents a limit of time and money for the formal education of many in this group. For others, it represents a level of scholastic attainment which satisfies their native abilities and tastes. It is also probable that many of the personnel requirements of industrial and engineering organizations are met by the four-year goal. Many believe that the universal prescription of a five or six-year course would not lead to commensurate gains for a large number of engineering students.

On the other hand, a consideration of the number of subjects required, and the various duties expected of a young engineer, indicates that the teaching of the fundamental principles basically underlying his work cannot be accomplished thoroughly in four years.

Four-year Program

The curricula offered in petroleum engineering by various institutions show considerable emphasis placed upon fundamental courses in mathematics, physics, chemistry, geology, and English.

Herewith is given a tentative division of the four-year program in petroleum engineering, showing the relative emphasis placed on each division in terms of semester hours credit. Courses in chemistry include: general inorganic chemistry, qualitative and quantitative analysis, organic chemistry, and physical chemistry. Some attention to colloids should be included in the course in physical chemistry.

Tentative Four-year Program

	Semester Hours
Chemistry	21
Drawing, engineering	6
Economics	3
English	12
Geology	18
Government	3
Mathematics	14
Physics	12
Civil engineering	12
Electrical engineering	3
Mechanical engineering	8
Petroleum engineering	22
General electives	6
Total	140

Courses in English, including some study of English literature, composition and report writing are important. A number of letters have indicated the desirability of a course in public speaking. A general thought from employers is that English is the most important subject in the curriculum.

While only 18 semester hours credit are shown for geological courses, it is believed that careful selection and design of such courses will result in a foundation upon

which the student may build if he contemplates graduate work. In addition to the usual courses in general and historical geology, the subjects of mineralogy, sedimentation, petroleum and structural geology, and subsurface correlation methods should be adapted to the particular needs of the petroleum engineer. Only slight emphasis is recommended for petrology, which should be concerned chiefly with the study of sedimentary rocks. The course in mineralogy should afford a satisfactory background for the subsequent study of subsurface correlation methods, which is believed to be the most important geological course for the petroleum engineer. Opinions may differ on this point, but the author draws this conclusion from field experience where the principles of geology were applied to production problems of all kinds.

Mathematics usually includes algebra, trigonometry, analytical geometry, differential and integral calculus. Many appear to be in doubt concerning the advisability of proceeding further with advanced calculus in the four-year program. It is believed, however, that additional courses in mathematics to include such subjects as mathematical theory of statistics, graphical methods, differential equations, and the more advanced studies, are desirable as electives for those who expect to continue with graduate work and research.

Courses in physics include the usual mechanics, electricity and magnetism, sound, light and heat.

In the civil engineering curricula, courses in strength of materials, applied mechanics, surveying, and hydraulics are recommended. A 3-hr. course in alternating and direct current machinery appears to be sufficient for the present from the courses available in electrical engineering. Courses in mechanical engineering include thermodynamics, metallurgy of iron and steel, and mechanical engineering laboratory.

A considerable emphasis has also been placed on advanced courses in fluid mechanics and thermodynamics. Since the application of these advanced courses is particularly unique and basic in production problems, adequate justification exists for the inclusion of these advanced studies in the petroleum engineering curricula.

Characteristic Technological Work

During the past few years the descriptive technologic type of petroleum engineering course has encountered criticism from several directions. Many of the petroleum engineering departments recognized this situation well in advance, and began to devise courses that would be as characteristic to petroleum engineering as the technological work of other engineering units. Although opinion has not crystallized entirely concerning the content of such courses, the literature reveals that the petroleum engineer has developed material that is distinct from other fields, and characteristic of petroleum engineering alone. For example, the flow of fluids through porous media, in all its intricate ramifications, *belongs* to petroleum engineering. Likewise, we can point to the pressure-volume-temperature-composition studies, and particularly their application to production problems. The flow of fluids in vertical pipes, and the artificial lifting of these fluids involve problems in thermodynamics and fluid mechanics that have been developed by the production engineer. The pumping of oil wells has presented problems involving energy losses which have become a definite part of the production engineer's daily attention. The study of the flow of drilling fluids has entailed special problems not met in the usual studies in fluid mechanics. This list, which can be extended in many other directions, justifies the conclusion that the application of basic principles to oil-field problems forms adequate justification for specialized

technological courses. Stephenson is already on record in his statement that "training in fundamentals must continue to receive greater emphasis, if we expect to meet successfully so many different kinds of problems. This means, then, that less stress shall be laid on the purely descriptive material and more on the theoretical, scientific base."

Graduate School

Provision for a longer training in graduate work is necessary if sufficient time is allowed in the undergraduate school for thorough training in the basic sciences, and for some appreciation of social philosophy, effective powers of expression, and the cultivation of reflective and critical habits of thought. It will, therefore, be necessary to carry over into the graduate school the advanced treatment of technical analysis and applications preparing for specialization. It is believed that such a rearrangement of the collegiate program and change of emphasis should not only permit thoroughness and breadth in the fundamental studies, but would encourage a greater degree of originality and imagination among engineering students. Specialization in the graduate schools also gives the student more time and opportunity to orient himself into his chosen work. As John R. Suman has aptly said: "There is no method of selecting students that does not give a considerable percentage of graduate misfits; and the extent of specialization should be some function of the perfection of selecting according to aptitude." Finally, not only does a good groundwork in basic subjects appear essential to the student, but it also provides him with the ability to turn to other branches of engineering, if, following graduation, he should so desire.

In line with procedures that have been suggested for other engineering branches, and an accelerating opinion in the industry, the emphasis to be placed on specialization appears to fit logically into the graduate program. It is obvious that these courses should be voluntary and individualized, rather than prescribed. They should apply fundamentally the basic principles presented in the undergraduate work to production and development problems. A proper selection of graduate petroleum engineering courses, correlated with appropriate subjects in other departments, may fit the student for the specialization that his aptitude more clearly indicates at this stage of his development. If specialization is not desired, the graduate studies could be broadened to meet the requirements of any rational program.

Basic Fundamentals

In conclusion, the student in petroleum engineering should, above all, have sound preparation in basic foundamentals. He must be able to analyze his problems and recognize, separately, the various elements involved. He should have a clear conception of those qualities requisite to engineering judgment; that is, skill in reaching the best possible conclusion under the limitations of allotted time and required accuracy. He must appreciate the importance of cost and of practical economics. He must be able to organize his thoughts and to express them clearly through speech and written English. He must be willing and able to adjust his personality to his environment. Finally, he should have a decided interest in continued professional development, and a sound philosophy of social values.

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DISCUSSION

W. T. Thom, Jr.,* Princeton, N. J.—Being deeply interested in engineering education, especially as it relates to work in the petroleum industry, I have just completed an analysis of the engineering and geological courses offered by about 60 schools. I am especially encouraged to note the close coincidence between Professor Power's views on engineering curricula and those to which I have come. My purpose is partly to register agreement with all that Professor Power has said and partly to add comment on two points not mentioned in his paper, which have a vital bearing on the critical time factors involved in the laying out of engineering curricula.

The first point stands out when one tries to plan an efficient and well-organized (college-level) schedule for engineering students; namely, the fact that so many course-hours now (supposedly) have to be scheduled for the teaching (or re-teaching) of courses in English, mathematics and modern languages—such as are normally offered in high schools and therefore *could* have been (and *should* have been) taken once and for all, at the pre-college level.

For students from good high schools or preparatory schools much, if not all, of this work is redundant and an inefficient use of time. Consequently, I submit that it would be a far better engineering proposition for us to insist that high school instruction be brought up to a standard level, instead of continuing to have college curricula distorted and overloaded merely in order to "cover up" on lacks in preparation of a part of the incoming Freshman students.

The other point to which I believe we should give attention is the effective use of summer periods for "off-campus" instruction. In years gone by students commonly were able to cover their own needs for practical experience by getting summer jobs of a sort in line with their projected professional work. Nowadays, most students find it very difficult to get summer work of any sort, and it is particularly hard to find jobs that correlate effectively with specific professional objectives. Consequently, it would seem to be vitally necessary that somehow an effective program for practical summer instruction be set up for the many (deserving) students who are not now able to secure summer experience through their own initiative.

The development of such a plan would appear to be a natural joint function of the colleges on one hand and of employing industry on the other—and it seems obvious that an organization like the A.I.M.E. *is* particularly well qualified to help with this problem because of its specific professional interests and its general membership-composition.

H. H. Power (author's reply).—I agree with Dr. Thom that high school instruction should be brought to a higher standard and made a prerequisite for entrance in engineering schools. Such a movement has been initiated at The University of Texas by requiring more rigid preparation in high school physics and mathematics. The results of inadequate preparatory school training are evident throughout the engineering training period. Better utilization of the four-year college program will be realized when the high schools assume their obligation to prepare their students adequately.

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Chapter VI. Refining

Review of Refinery Engineering for 1940

By Walter Miller,* Member A.I.M.E.

(New York Meeting, February 1941)

Petroleum refining, like other industries in the United States in 1940, focused much attention on its duties and opportunities in the field of national defense. In counter-distinction to the situation during the World War, the industry is well constituted as to existing equipment, processes, and capacity, together with planned additions, to handle any demands that may be made upon it by the defense program needs. Evident throughout was the growing sense of ability to manipulate oil molecules for the production of materials not hitherto considered as being available commercially from petroleum. The development and application of catalytically induced reactions on a broad front is one of the distinguishing characteristics of refining progress during the year.

In the hands of the refiner, catalysis has developed into a most important means to secure higher antiknock motor fuels and 100-octane fighting grade aviation gasoline in greatly increased quantity. One illustration of the importance being assigned to catalytic refining is the construction by the Houdry group of an experimental laboratory at a cost of $700,000, to be staffed with over 100 research men, solely for the purpose of studying catalytic reactions.

In the aviation gasoline picture a modification of specifications by the Government widened the field from which acceptable fuel can be secured, and the continued expansion of the alkylation process in itself promises to go far in filling the demands expected from 50,000 fighting planes. It is conservatively estimated that even now the industry can turn out 1,300,000 gal. of 100-octane aviation gasoline daily.

The upper limits of octane numbers for regular grades of motor gasoline reached in 1939 were not exceeded, but the average octane number approached the upper level more closely. A survey made of the 1940-model cars showed no rise in average octane requirement of the engines. The trend throughout the year was for greater reliance on the A.S.T.M. method for octane determination. The "1939 Research Method" is less widely used, although still considerably in evidence; the older L-3 method seems to have lost considerable ground and to be on the way out.

Re-forming Capacities Increased

Interest continued to grow apace in re-forming low-octane naphthas into high-octane gasolines. Some additions, although not great, were announced in thermal re-forming capacity. Interest in catalytic re-forming was greatly stimulated by the technical success of the operation of the converted hydrogenation unit at the Bayway, N. J., refinery of the Standard Oil Company of New Jersey, mentioned in last year's review, and also by the knowledge that recoverable proportions of toluene are present in the hydroformed (catalytically

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re-formed) distillate. The dehydrogenating reaction involved in hydroforming produces an end product containing substantial proportions of aromatics and other cyclic compounds, the distillate obtained from normal operation containing from 5 to 8 per cent of toluene, which can be separated and purified for T.N.T. manufacture. A 7000-bbl. hydroforming unit at the Texas City refinery of the Pan-American Petroleum and Transport Co., went into operation late in the year, with, however, no information yet available as to operating results. A 4000-bbl. unit is being installed at the Continental Oil Company's refinery at Ponca City, Okla., which will be ready for operation early in 1941. A 16,000-bbl. per day plant, plus auxiliary units for the separation and purification of an estimated 27,000,000 gal. of toluene per year, was provided for in a contract between the War Department and the Humble Oil and Refining Co., to be erected adjacent to the latter's large refinery at Baytown, Texas. Although no public announcement has been made, it is rumored that two more units of somewhat similar size are planned for installation at other refineries, but without provision, at least for the time being, for toluene recovery. Early in the year the Sun Oil Co. announced the expenditure of $1,000,000 for a Houdry-process re-forming unit having a charging capacity of 10,000 bbl. at its Marcus Hook refinery.

In the older cracking field making gasoline from gas oil and heavier products, thermal cracking accounted for less total volume of newly installed capacity than did catalytic cracking; thermal installations, except for one 8000-bbl. still, being confined to comparatively small units, ranging from 3000-bbl. charging capacity downward. The Tide Water Associated Oil Co. announced a project for building a Houdry unit with 15,000 bbl. per day charging capacity at its Bayonne, N. J., refinery. The Sun Oil Co. completed a 20,000-bbl. Houdry unit, and two or more such units of the Socony-Vacuum Oil Co. were completed and put in operation during the year, these being a part of the program announced by the two companies in their Houdry paper read at the 1938 annual meeting of the American Petroleum Institute.

A Moving Catalyst Bed

What may prove a most important step in catalytic cracking has been worked out on a 100-bbl.-a-day pilot plant by the same group that is licensing the hydroformer process for catalytic re-forming, the group including The M. W. Kellogg Co., Universal Oil Products Co., and five or six of the larger oil companies. This step is that of using a "moving catalyst bed" type of operation as distinguished from the "fixed catalyst bed" multiple-reactor operation described and used by the Houdry group. It involves introducing the catalyst in the form of a fine powder into the body of the vaporized gas oil being catalytically cracked, keeping the two in contact long enough to bring about the desired reaction, followed by mechanically separating the catalyst from the cracked vapors and putting the catalyst through a reactivator or regenerating unit. The entire operation is continuous, as distinguished from the intermittent operation of the fixed-catalyst-bed process. Lower cost of installation, greater economy in operation, and excellent yields of high-octane gasoline are claimed. No printed announcement has yet been made of the process by its sponsors, and no detailed data are available for publication, but the operation of the 100-bbl. unit has been shown and explained to a considerable group of interested refiners. At least one installation, to process 15,000 to 20,000 bbl. of raw material a day, is under design and construction, and is expected to be in operation in time to make large-scale results available in the latter part of 1941.

Polymerization

Polymerization of gases has come to be accepted as an indispensable tool of the

refiner, at least in all plans using thermal cracking and thermal re-forming. Catalytic polymerization, limited to combining the unsaturated portion of the gas produced in such cracking and re-forming units, led in number of installations, most of them in comparatively small refineries, but at least two thermal polymerization plants were installed under conditions where the combined volume of available oil-field and refinery gases, as well as conditions peculiar to the particular refinery, justified the larger investment. A possible future commercial catalytic application was indicated in a report by Egloff and associates pertaining to the selective dehydrogenation of butane and propane, as a preliminary step to catalytic polymerization.

Desulphurization

Desulphurization of gasoline provided another commercial application of catalysis. Great general interest in this subject was evinced, many studies being published showing the advantage from the standpoint of antiknock improvement gained through removing excess sulphur and even fairly small amounts of sulphur from gasoline already within the percentages allowed by standard specifications. At least one commercial installation was made for reducing the sulphur content of gasoline by bringing it while in a hot vapor state in contact with a catalyst, and it is to be expected that catalytic desulphurization will be given much more study and commercial application. It promises to improve the quality of gasoline and, by virtue of raising the octane number and increasing the lead sensitivity, reduces the amount of tetraethyl lead required to reach a given octane value.

Bottled Gas

The mushroomlike expansion of the demand for "bottled gas," from 39,000,000 gal. in 1932 to 223,000,000 gal. in 1939, has been responsible for the installation, in many refineries not previously so equipped, of fractionating equipment to segregate and make available the propanes and butanes as liquefied petroleum gas. Although of relatively minor quantitative importance compared with the volume of gasoline produced, this practice offers a higher-rank outlet for material otherwise largely used as a constituent of fuel gas.

Lubricating Oil

Little new construction work was reported in the field of lubricating-oil manufacture. One new installation was made with a total capacity of 50,000 bbl. per month of finished oils, a single solvent process for light oils and a two-solvent unit for the high-viscosity products comprising the equipment. Being a replacement of and supplanting older methods of refining, no net increase in production is involved. Demand for paraffin wax, still unusually good early in the year, was greatly reduced as the export market was largely shut off. Two new solvent-dewaxing installations were made, one a replacement, the other at Pasadena, Texas, representing new capacity. Two commercial installations were made of a new wax-refining method called the Emulsion De-oiling Process, one in the Pennsylvania field and the other in the Mid-Continent. In this process the oily wax in liquid state is emulsified with water, chilled to crystallize the wax, and centrifuged in basket-type centrifugals to remove oil and water. By repeating the melting, emulsification, crystallization, and centrifuging one or more times, the wax is brought to specifications without difficulty. The advantages compared with the orthodox methods are said to be the reduction in volume and cost of equipment, the speed with which the process can be carried out, and the close control possible.

"Vitamins" for Oils

Although the construction engineer was inactive on lubricating-oil and wax-plant installations, the research chemists and technologists were more active than ever

in studying and developing new "vitamins" (addition agents) for the oils. The search for compounds which, added to the lubricating oils in small proportions, would inhibit oxidation or corrosion, prevent engine lacquering, reduce breakdown of the oils, and ensure cleaner motor conditions was prosecuted more intensively and on a wider scale than ever before. A number of previously used substances were replaced by newer, more effective agents. Sulphurized natural and synthetic esters, sulphurized aliphatic olefins, organic phosphites and phosphates, chlorinated compositions, and primarily the metallic soaps and other substances with detergent qualities, all came within the purview of the avid searchers for new agents and new uses and improved applications of known substances.

That the refining industry extended much further into the chemical field, as a supplier of base material and in the manufacture of organic chemicals, is shown by the fact that more than a fourth of new construction reported for and in connection with the oil industry was for such purposes. Among the products so provided for are tetraethyl lead, nitroparaffins, solvents, artificial rubber, and toluene, already mentioned.

Synthetic Rubber

Because of the immediate and widespread effect that cutting off natural rubber supplies would have, production of synthetic rubber has received much publicity and great study. Researchers for years have been investigating rubber constitution and synthesis, with the result that a considerable variety of artificial rubbers have been developed, all of them using as base materials unsaturated hydrocarbons which either are now produced from petroleum or are possible of being so produced.

Several types of synthetic rubbers, with properties superior to natural rubber in particular respects but relatively expensive to produce, have been manufactured commercially for several years. Under the impetus of national defense, however, a much more extensive program of expansion got under way. Standard Oil Development Co., a subsidiary of Standard Oil Company of New Jersey, is taking an important part in the work. A plant for the production of 10,000 lb. a day of artificial rubber from butadiene and acrylonitrile is under construction by the Standard Oil Company of Louisiana, another subsidiary of the Standard of New Jersey. A new company to bring together the research and facilities of the B. F. Goodrich Co. and Phillips Petroleum Co. is planning an initial production of 2000 tons a year from butadiene and other chemicals not disclosed. Also, du Pont is said to have increased its production of Neoprene to 15 tons a day. The Rubber Reserve Corporation, subsidiary of Reconstruction Finance Corporation, has been formed to negotiate increases in supplies with potential manufacturers, and discussions envisioning facilities for making up to 150,000 tons a year are said to be in progress, involving at least half a dozen possible sources.

Toluene and Glycerin

Of equal importance to defense is the manufacture of toluene. Although the annual toluene production from coal-distillation plants considerably exceeds the peak reached in 1918, a great demand has been built up since then for solvent and other uses. The increased supplies entailed by the defense program, therefore, must if possible be found elsewhere. The petroleum industry provides this new source. Two immediate toluene sources are open to petroleum refiners, both being utilized in operating or projected plants. The first is in a few naturally occurring petroleum deposits, which contain toluene in amounts recoverable by distillation. The Shell Oil Co. produced the first barrel of toluene from its new commercial distillation plant on Dec. 7, 1940. This plant is designed for

an output of 2,000,000 gal. a year. Possible supplies from such sources are necessarily limited and will not go far in meeting the 50,000,000 to 60,000,000 gal. per year estimated as defense-program needs. Synthetic manufacture by special catalytic re-forming, as previously noted, will be relied on for the bulk of the new production. The three hydroforming units previously listed as being under construction should, according to present knowledge, be capable of providing about 35,000,000 gal. per year.

In addition to toluene, the industry has available for rapid commercial use processes for manufacturing glycerin, from which nitroglycerin, dynamite, and cordite may be made, and glycols, also base materials for explosives. Manufacture waits only for the demand to exceed the supply available from natural sources.

Petroleum Derivatives

As potentially important as are artificial rubber and toluene, use of petroleum derivatives in less warlike chemical manufacture is also of great importance. The Carbide and Chemical Corporation is constructing a large plant at Texas City, Texas, similar to the one that has been operating at Whiting, Ind., for several years, to manufacture organic chemicals from the refinery gases produced by the Pan-American Petroleum Co.; Ethyl Gasoline Corporation is utilizing liquid and gaseous petroleum products in its plant at Baton Rouge, La., in manufacture of ethyl fluid; and in 1940 the Commercial Solvents Corporation for the first time produced commercially nitroparaffins, the result of nitrating the lighter hydrocarbons.

The importance to the nation of petroleum as a source of chemicals, and the importance to the oil-refining industry of chemicals as products is well typified by the American Institute of Chemical Engineers giving one-third of its attention in its annual meeting in December to advances in the oil industry.

Summing it up, 1940 was truly a great progress year for petroleum refining, particularly from the dual standpoints of catalytic development and chemical manufacture.

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(NOTE: In this index the names of authors of papers and discussions and of men referred to are printed in SMALL CAPITALS, and the title of papers in *italics*.)

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